OUTBACK OUTLOOK NEW AUSSIE MEGASCOPE SEEKS ALIENS & BIRTH OF UNIVERSE

COSMOS

THE SCIENCE OF EVERYTHING

ISSUE 98

COSMOS THE SCIENCE OF EVERYTHING

BEYOND THE PALAEO

DULL DINOSAURS GET THE MAKEOVER THEY DESERVE

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Seeing emotions
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DUMPING DIESEL FOR MICROGRIDS • THE SCIENCE AND ART OF AIR • COOL BANANAS

Above WA: a satellite-streaked sky

Lit by reflected sunlight, countless satellites cross the skies above the Pinnacles Desert, in Nambung National Park, Western Australia, their time-lapse trails forming an alluring mantle. The delight of this magical image – shot by hobby astrophotographer Joshua Rozells and composed of multiple frames over 85 minutes – is lost, however, once context is added. About 400km north-east, on Wajarri Yamaji Country, the SKA-Low's 130,000 individual antennas are under construction at Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory. SKA-Low is smack in the middle of the Australian Radio Quiet Zone WA – but how quiet is it likely to be with this nightly mosaic? Increasing numbers of low-Earth-orbit satellites pose a genuine threat to scientific understanding of the distant universe. To learn more about SKA-Low (and its possible satellite problem) turn to page 46.

JOSHUA ROZELLS (INSTAGRAM / @ JOSHUA_ROZELLS)

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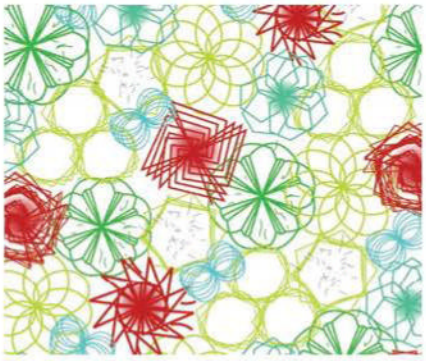

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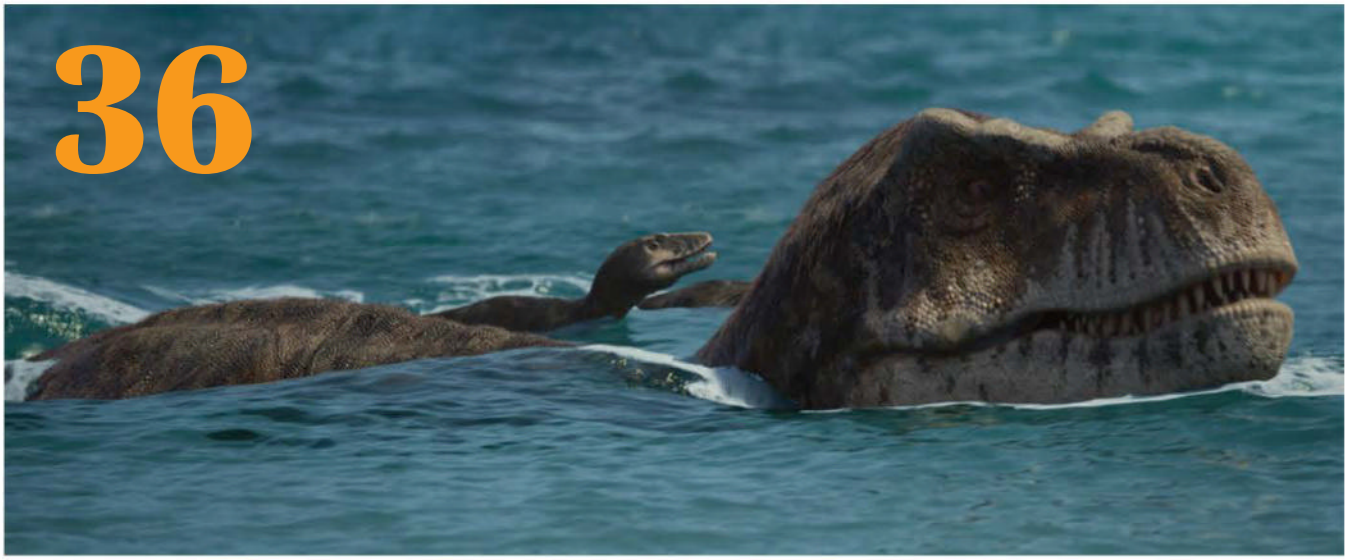

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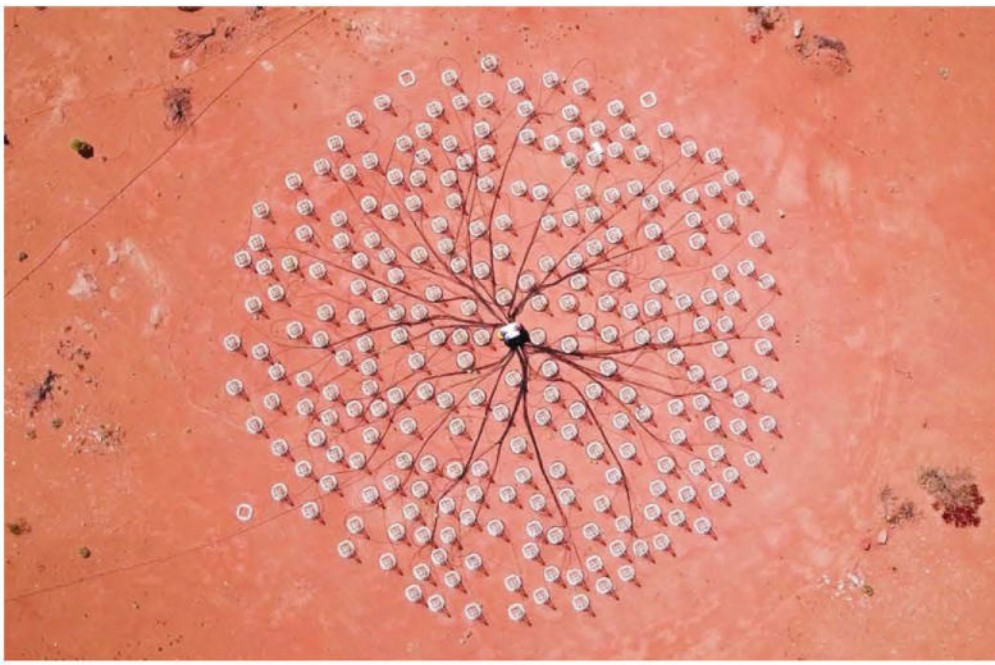

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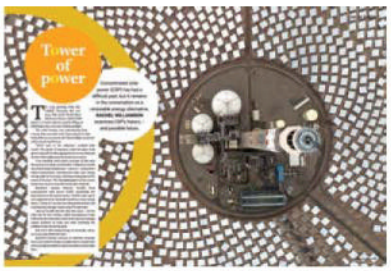

ISSUE 97 OF COSMOS has an interesting article on solar power. The article talks about a 16,000m³ pit which is (indirectly) used to boil ammonia. In parenthesis it then says "which has a boiling point under 90°C"...The 'regular' boiling point of ammonia (NH_3) though is around -33°C. Is the ammonia referred to in the article under a lot of pressure, or is it an ammonia compound rather than ammonia? Or are you simply saying that -33°C < 90°C?

Thanks, Walter Hill

From story writer Rachel Williamson:
There's an easy answer: Raygen boils the ammonia at a specific temperature, somewhere less than 90°C, by controlling the pressure. The company founder wouldn't tell me precisely what that temperature or pressure was, because the information is commercial in confidence. Because they're heating water with superheated rays from solar panels, the temperature at which they boil the water must be higher than 0°C but less than 100°C, and the founder confirmed that the top range of temperature they use to boil the ammonia is less than 90°C. But Walter, you are right: – ammonia's true boiling point is -33°C.

IN THE ARTICLE titled "The Science of Sci-fi", I make the following comments on his discussion of "artificial gravity".

It seems to me that in a space station of radius 200m, spinning at 2 revolutions per minute, a person walking on the inside of the rim may find themselves leaning a few degrees against the direction of the spin. Moreover, I doubt that "spin gravity" could completely eliminate bone density and muscle loss, because the force acting on the body is "compressive", acting upwards through the body, by direct molecular contact within tissues and bones, whereas true gravity acts separately on every atom of the body.

Robert Claire

From Prof. Alan Duffy:
Thanks for sharing! It's a wonderfully insightful comment. Certainly, you will experience a differential force (the head will experience a different force to the feet). In the extreme case – if the radius was 180cm – then my head would be in the zero-g centre! I couldn't agree more to the need for long-duration testing of the impact as well – we can only learn by doing as soon as possible in my opinion. One thing I can also agree on is that it won't be a perfect substitute for life on Earth – however it must surely be better than what our astronauts currently experience.

I'M FRUSTRATED at the print and backgrounds used in the magazine's layout. I'm 82 years old and my eyesight is not as good as it was 20 years ago. I have difficulty reading articles written in white text on a coloured background. This occurs frequently and is very frustrating.

Regards, Des Butler

From: Gail MacCallum, editor
I'm so sorry! We want everyone to explore our world, and letters like yours remind us to make sure we're making that as accessible as we can.

Starting with this issue we're tweaking the magazine's design. We're hoping that the changes help to keep you engaged.

Get in the loop Write to us with comments, complaints or questions at contribute@cosmosmagazine.com

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From the Editors

HOW TOTALLY GREAT IS IT knocking around with scientists who are aiming for radical *uncertainty*? "Since the beginning of finding dinosaurs, people have been making them grey and brown," says Jack Horner, renowned palaeontologist (and literally living idol of his interviewer, *Cosmos* journalist Evrim Yazgin). "I say, since we don't know, a vividly coloured dinosaur is just as accurate as a brown one." For more on how ever-better research methods – and unbridled creativity – change what we know about dinosaurs, and how we colour them every which way, turn to page 36.

What new adventures await with new research? Jacinta Bowler takes a trip to remote WA to learn about the now-building SKA-Low radio telescope (and its possible inhibitors); it could find aliens and open new knowledge of the birth of the universe, but there are problems on the horizon to overcome. Petra Stock gets inside the headset-and-goggles for a close look at the developing field of emotional AI: fine, fair, or foul? In another eerie AI space, Charlotte Jee considers for and against in the growing field of digital clones of the dead. *Yes mum, I brushed my teeth; wait a minute – didn't you die a year ago?* It's a tech some find confronting, others comforting.

Back where it's real, Martin J Kernan meets the scientists whose careful work has been proven to control the plant-killing glassy winged sharpshooter; Lauren Fuge climbs a Tasmanian blue gum that's nearly as tall as the Statue of Liberty – and finds an unexpected view and sobering take on the world's natural systems; Jamie Seidel constructs what a working day looks like for the first next-gen human Moon explorers; and staff writer Imma Perfetto goes bananas: potassium appeal.

And then there's Ashley Hay's story, which completes this issue's circle on art and science reimagining our world. Hay's subject is Argentinian artist Tomás Saraceno, whose interest (obsession?) is air. It surrounds us and supports us. We dwell within it; travel through it; and ignore, ignite and defile it. Its growing concentrations of greenhouse gases defines our age. Perhaps, like reimagined dinosaurs, we ought to think of it in vibrant colours – lest listless hues forever shape our hopes for the future.

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DIGEST

R. KOTHES (NRC) AND THE EMU AND POSSUM TEAMS

▶ ASKAP telescope image of the Galactic SNRs. See page 17.

PALAEONTOLOGY

Amateur palaeos nab pristine plesiosaur

100-million-year-old fossil dug up in Australian outback might be a new species.

AUSSIE FOSSIL HUNTERS have unearthed the continent's first elasmosaur fossil in western Queensland.

The 100-million-year-old head and body bones of the marine reptile were uncovered by three fossil enthusiasts who regularly trawl the ranges of their privately-owned outback station searching for ancient remains.

Their previous expeditions have found the remnants of kronosaurus, ichthyosaurs, and prehistoric fish and turtles.

What's most exciting about the elasmosaur discovery is the retrieval of both body and head fossils at the same time – a new milestone the Queensland Museum has described as like finding the Rosetta Stone for marine palaeontology.

Elasmosaurs are a type of plesiosaur – a long-necked marine reptile – that coexisted with dinosaurs during the Cretaceous period (contrary to popular belief, not all large ancient reptiles are of the dinosauria grouping).

"We have never found a body and a head together and this could hold the key to future research in this field," says Dr Espen Knutsen, the senior scientist and palaeontology curator at Queensland Museum.

Few things seem as counterintuitive as finding the remains of a long-necked marine reptile in the dry Australian outback. But such is the passage of time. During the Cretaceous period (146–65 million years ago) when elasmosaurs swam the Earth, much of the landmass today associated with Queensland was submerged beneath a shallow sea and located at latitudes much closer to the Earth's south pole.

The presence of this land-covering sea is why the region is today home to the regular discovery of marine reptile fossils.

The discovery adds to an expanding collection of specimens from this taxonomic clade at the Queensland Museum, and finding a body and head together could unlock a new species.

Knutsen's team will take the specimen into the lab for CT scanning and 3D modelling to provide finer detail as to the biology of the animal.

At the very least, the discovery will further the museum's understanding of the diversity of plesiosaurs in Australia hundreds of millions of years ago.

"It's going to tell us a lot of about the taxonomy, or the species diversity – how many of these were around at the time," says Knutsen. "We're trying ... to further knowledge of these fauna. It's a great moment."

QUEENSLAND MUSEUM NETWORK

SPACE

Asteroid probe's tiny payload yields big result

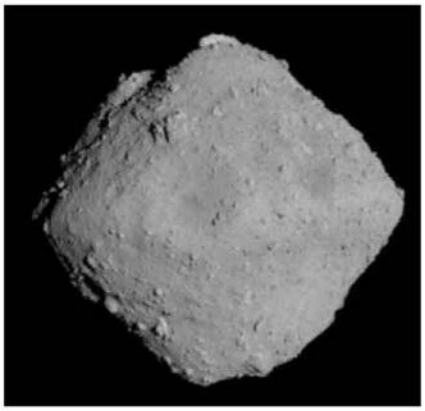
New analysis confirms asteroid Ryugu's classification among most primitive material.

IN THE TWO years since Japan's Hayabusa2 jettisoned a small capsule to eagerly waiting scientists in the desert of South Australia (see Issue 88), researchers have been picking through its contents, keen to unearth the secrets of our early solar system.

The capsule contained just 5.4 grams of material from the asteroid Ryugu, which Hayabusa2 scooped up in a landmark mission in late 2018. French scientists have obtained further insight into the chemistry and origins of the asteroid and furthered our understanding of the early Solar System.

Asteroids are often compared to rubble leftover from a building site, as many represent some of the most primitive and pristine material from the earliest days of the Solar System's formation. Meteorites, although prized by researchers, are inevitably contaminated by their passage through Earth's atmosphere and exposure to weather and other terrestrial processes.

Since the samples from Hayabusa2 are directly from the asteroid, they are a game-changer for research into the earliest origins of our solar system. So far, analysis has already shown that Ryugu is close in composition to 'Ivuna-like' carbonaceous chondrites ('Ivuna' is the type-specimen for this type of meteorite).



Asteroid Ryugu was visited by JAXA spacecraft Hayabusa2 in late 2018.

This type of chemistry is typical of primitive host asteroids and is similar to the composition of the Sun. Ryugu has also shown a few puzzling isotopic signatures which overlap with other classifications of carbonaceous chondrites.

New analysis has more deeply investigated the isotopic ratios of zinc and copper within the samples. These elements are key to understanding how volatiles are gathered and incorporated into the structure of terrestrial, or rocky, planets. This research, recently published in *Nature,* confirms that Ryugu clearly delineates itself from other types of carbonaceous chondrites, confirming that it is actually Ivuna-like.

Importantly, the measurement of copper and zinc isotopes has also provided the best estimates for the amounts of these elements in the 'solar composition' (the chemistry of the Sun and early Solar System). Measurements of the isotopic composition of zinc, in particular, are useful for understanding the process of forming habitable planets such as Earth. The research also indicates that Earth contains about 5% of Ryugu-like mass, providing key insights into the formation of Earth.

The OSIRIS-REx mission, which hopes to have collected a whopping 60g from asteroid Bennu, is due back to Earth this September.

ISAS/JAXA

DISCOVERY

Plate colour can influence picky eaters' taste perception

THE TRUISM "you eat with your eyes first", is certainly the case for picky eaters, according to a study published in *Food Quality and Preference.*

Researchers from the University of Portsmouth, UK, investigated whether changing bowl or plate colour could affect picky eaters' perceptions of how food tastes.

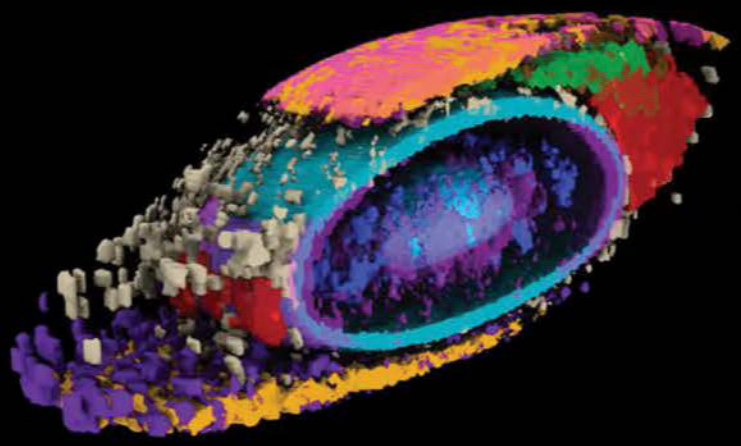
They found chips served in blue bowls were considered saltier and more desirable compared to other colours. The colour of the bowl didn't affect how non-picky eaters perceived taste.

There's a serious side to this research.

People with "food neophobia" – a reluctance to eat or try new foods – may consume fewer than 20 different food items over their lives, potentially leading to nutritional deficiencies and health problems. There are social implications too, with the potential for mealtimes to lead to conflict or anxiety, the paper says.

The study notes that research into picky eating commonly focusses on children, even though around 18% of adults are considered picky eaters.

MEDICINE



Scientist unlock the secrets of what human cells really look like

Not all cells are the same.

RESEARCHERS ARE CLOSER to answering the surprisingly complicated question, 'what does a cell look like?' after working with 200,000 images of stem cells of various sizes and shapes.

Although most of us would have seen a diagram of a mammal or plant, usually these designs are rough descriptions, not actually how the cell's organelles and interior would be organised.

And even within just one type of cell – for example a human induced pluripotent stem cell – there can be a huge variation.

"The way cells are organised tells us something about their behaviour and identity," said one of the researchers, Allen Institute for Cell Science deputy director Susanne Rafelski.

"What's been missing from the field, as we all try to understand how cells change in health and disease, is a rigorous way to deal with this kind of organisation."

To understand what cells looked like inside, the team started a collection of stem cells genetically engineered to light up 25 different internal structures and organelles under a fluorescent microscope. They then took 3D images of more than 200,000 different cells.

Even though the cells under study were genetically identical and reared in the same laboratory environment, their shapes varied substantially – some were long and pear-shaped, others were short and blobby and many were shapes in between.

By using mathematical frameworks, the team developed a 'shape space' that described what the stem cell looked like. These were basic characterisations like height and volume, but also 'pear-ness' and 'bean-ness'. The researchers could then look at the cellular and organelle structure of similarly shaped cells – comparing pears to pears.

Looking at the 25 organelles they found that the internal structure was incredibly similar within the groups with similar shapes.

▲ Integrated average morphed cell showing distinct structures.

"We know that in biology, shape and function are interrelated, and understanding cell shape is important to understand how the cells function," said Matheus Viana, Allen Institute for Cell Science senior scientist.

"We've come up with a framework that allows us to measure a cell's shape, and the moment you do that you can find cells that are similar shapes, and for those cells you can then look inside and see how everything is arranged."

As well as giving scientists a much better understanding of how stem cells are put together, the researchers are hoping that it will allow scientists to look out for interesting deviations in the 'normal' cell structure – for example when the cell is dividing into two.

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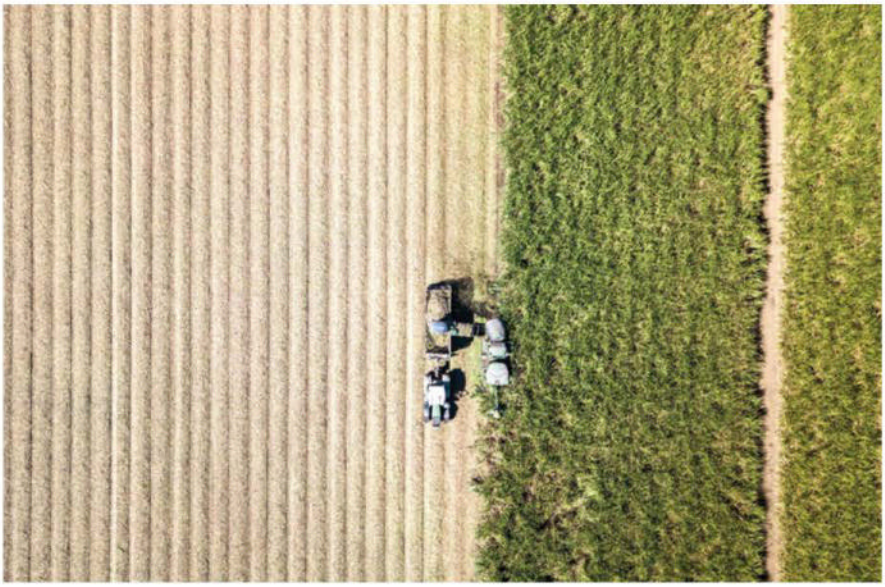


ENVIRONMENT

New enzyme speeds sugar's change to biofuel

No cells, no worries.

AUSTRALIAN RESEARCHERS HAVE found a way to more effectively convert sugarcane into the building block of aviation fuel, and other products such as rubber and plastics.

Sugarcane is one of the crops that has shown promise in being turned into "biofuel", which could one day lower aviation's reliance on fossil fuels.

The research team – based at the University of Queensland and the Technical University of Munich – was able to create an enzyme called PuDHT that sped up the step from turning sugar into pyruvate and then into a useful feedstock chemical called isobutanol.

Isobutanol is a bit like self-raising flour for chemists. It's a versatile "ingredient" that can be used to make anything from fuels, plastics, rubbers and food additives.

The team also tested using manganese and magnesium ions to speed up the process even more.

"Our research into this particular enzyme means we can accelerate the production rate and yield of isobutanol from sugarcane," said UQ biochemist Professor Gary Schenk.

Cell-based production of isobutanol from sugar creates about 25 grams per litre of liquid cell culture, but, the "cell-free" method in the new study produced at least 10 times that amount.

If researchers can secure enough enzymes at a cost that is economically viable, this method could be used in 'bulk' products like aviation biofuel.

"While there have been commercial limitations to producing the enzymes, we now have enough evidence to show that large-scale manufacturing using the cell-free enzymes process is commercially viable and should play a major role in future biomanufacturing," said Professor Damian Hine, also from UQ. The research is published in *Chemistry – a European Journal*.

CLIMATE

Could we predict future cyclone paths?

Tropical cyclones are hard to predict and, once formed, their movement can be very erratic.

A research team at Griffith University in Brisbane aims to better understand cyclone behaviour by examining five decades of historic cyclone tracks around Queensland.

Existing cyclone-track records – such as BoM's – aren't perfect for analysing and predicting cyclones in more detail. So the researchers calculated cyclone power, track curvature (the wiggliness of the path) and location using an algorithm to reduce the effect of faulty records.

With this analysis, the researchers were able to divide Queensland cyclones into three different geographic "clusters".

While cyclones are probably becoming less frequent as the climate warms, they may also be getting more intense when they *do* form – and affecting more people.

Next, the researchers are aiming to see what's driving cyclone behaviour – including climatic changes. After that, they'll be investigating how the cyclones change waves and swell.

MEAGHAN SKINNER PHOTOGRAPHY/GETTY IMAGES

PALAEONTOLOGY

Benign neglect: titanosaurs left their babies to fend for themselves

Over 250 titanosaur egg fossils were found at a nesting site containing 92 nests.

MARK GARLICK / SCIENCE PHOTO LIBRARY / GETTY IMAGES

DID DINOSAURS MAKE good parents? Ask that question several decades ago and you would have heard a resounding "no" from most palaeontologists. Back then, the "terrible lizards" were still seen as one-dimensional, scaly monsters. But our understanding of dinosaurs and their behaviour is much changed.

In the late 1970s, palaeontologist Jack Horner discovered *Maiasaura* – a duck-billed dinosaur that was the first recorded to exhibit feeding and care-taking of hatchlings. The animal's scientific name means "good mother lizard" (See Horner's illustration of it in Tyrannosaurus next, page 36).

As consensus developed in the 1980s and '90s that modern birds are descended from the dinosaurs, it provided further verification. Birds are known for paying close attention to their young; it makes sense that this is inherited behaviour.

But it seems not all dinosaurs were built for parenthood. A fossilised nesting site dating to the last part of the Cretaceous period (72–66 million years ago) was found in the Narmada Valley in central India. The discovery is detailed in a paper in *PLOS ONE*.

Together with previously known sites, the new nesting sites "constitute one of the largest dinosaur hatcheries in the world", says co-author Guntupalli V.R. Prasad, from the University of New Delhi.

Among the 92 nests were a total of 256 fossil eggs from titanosaurs – the largest of the dinosaurs, and the largest land animals of all time. The largest of them are believed to have measured nearly 40 metres in length and weighed 70–100 tonnes.

A herd of titanosaurs.

It's not exactly clear which species laid the eggs found in the Narmada Valley. But palaeontologists have identified six different egg-species (oospecies), which is more than the number of titanosaur species known in the region from skeletal fossils.

The layout of the nests and the lack of space between them suggests that the mothers would lay eggs and move on – leaving their hatchlings to fend for themselves.

"Our research ... offers new insights into the conditions of nest preservation and reproductive strategies of titanosaur sauropod dinosaurs just before they went extinct," says lead author Harsha Dhiman from the University of Delhi.

PHYSICS

New type of quantum entanglement helps "see" inside atoms

Scientists may have struck gold (ions) with discovery.

NUCLEAR PHYSICISTS HAVE used a never before seen type of quantum entanglement to help them gain information about the inside of an atomic nucleus.

At the Relativistic Heavy Ion Collider (RHIC) – at the Brookhaven National Laboratory, US – physicists were able to use the photons (particles of light) surrounding gold ions passing through the collider to observe the structure of atomic nuclei and entangled pairs of particles.

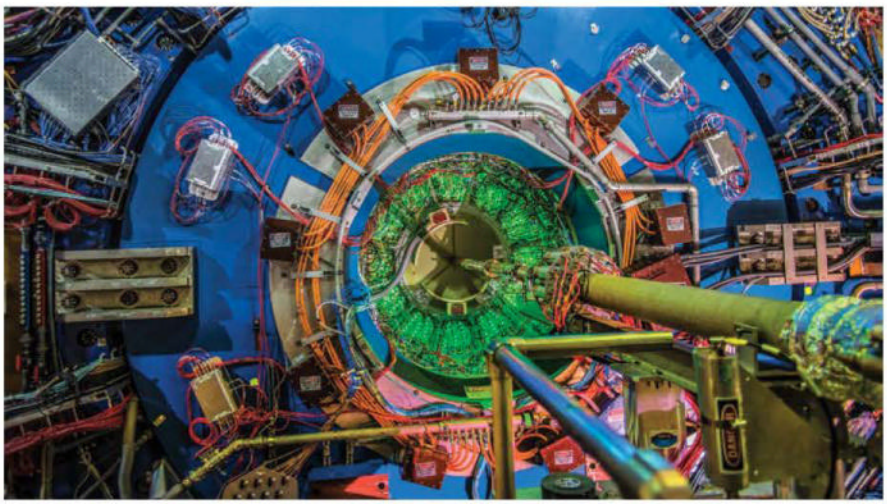
Quantum entanglement links the physical states of particles, no matter how much they are separated. Until now, it's only ever been observed between particles of the same type – e.g. entangled pairs of electrons or photons.

In their experiment, the nuclear physicists observed photons interacting through a series of quantum fluctuations with gluons in gold ions, zipping through the RHIC. Imaginatively named, gluons are – wait for it – glue-like particles responsible for the strong force which holds quarks – which in turn make up protons and neutrons in atomic nuclei – together.

A new intermediate particle is produced by the interaction between the photons and gluons. This particle quickly decays into opposite charged particles called "pions" (denoted by the Greek letter π). The velocity and trajectory of the π+ and π- can be used to get crucial information about the photon and work out the arrangement of gluons in the nucleus more accurately than ever before.

"This technique is similar to the way doctors use positron emission tomography (PET scans) to see what's happening inside the brain and other body parts," says former Brookhaven physicist James Daniel Brandenburg, now at Ohio State University. "But in this case, we're talking about mapping out features on the scale of femtometres – quadrillionths of a metre – the size of an individual proton."

The house-size STAR detector at the Relativistic Heavy Ion Collider (RHIC) acts like a giant 3D digital camera to track particles emerging from particle collisions at the centre of the detector.



BROOKHAVEN NATIONAL LABORATORY

NATURE

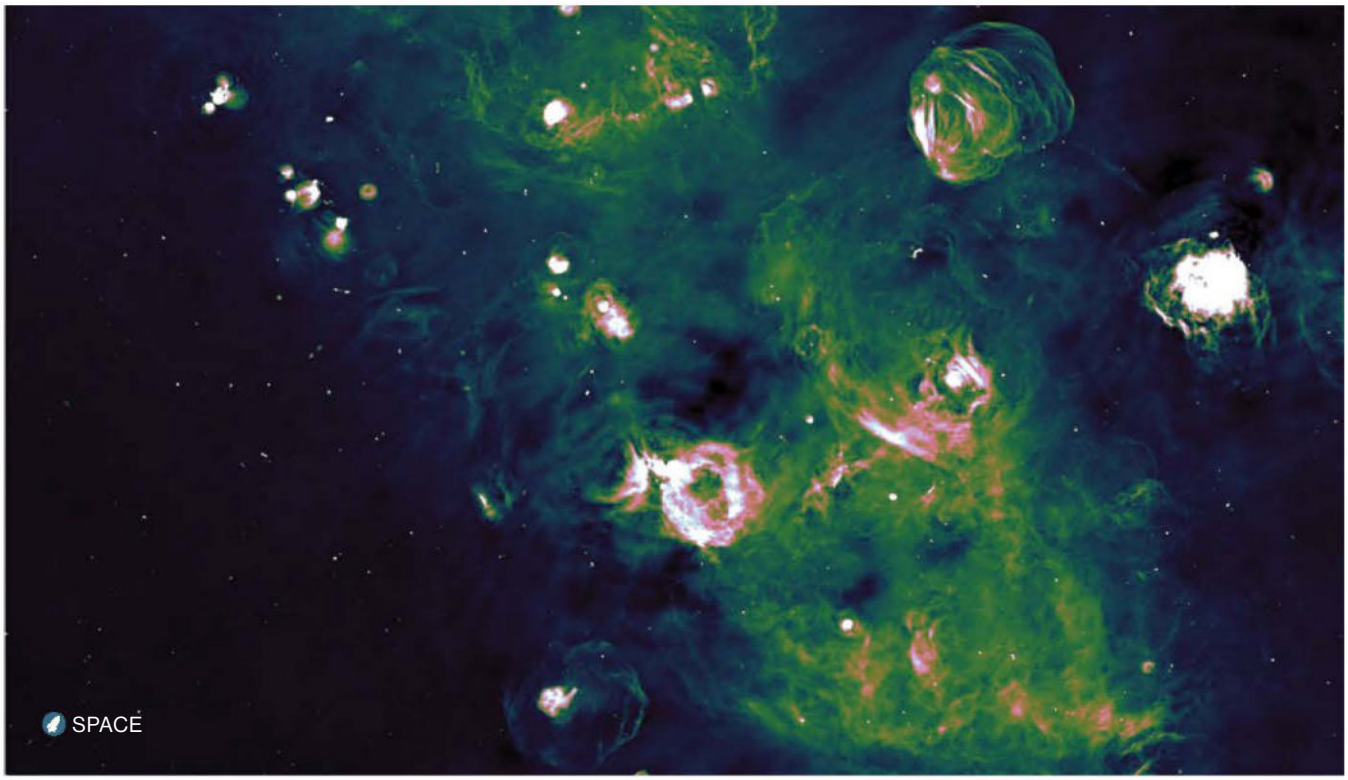
How jet-propelled gelatinous marine organisms could inspire underwater vehicle design

NANOMIA BIJUGA IS a marine animal related to jellyfish that swims with the use of jet propulsion. But unlike octopuses and squids, which use a single jet to propel through the water, it uses a multi-jet approach.

A dozen or more structures on its body, called nectophores, pump water backwards to push it forwards. The animal can control the jets individually – syncing them up or pulsing them in sequence.

According to a new study published in *PNAS*, the two different swimming styles actually allow Nanomia to prioritise speed or energy efficiency, in the same way many fish have distinct swimming modes that differ between steady, routine swimming and the speed needed to escape from a predator.

Researchers at the Oregon Institute of Marine Biology, US, believe this strategy could be used to design underwater vehicles that can change propulsion to fit different needs.



Australian telescopes' image provides glut of rare supernova remnants

We see so few – but so many stars have lived and died.

A COMBINED IMAGE from the Parkes radio telescope and the Australian Square Kilometre Array Pathfinder (ASKAP) has given scientists the most detailed radio image yet of our galaxy.

The image highlights hydrogen gas– likely from supernova remnants (SNRs) or new stellar nurseries, and the team is hoping it will shed much more information on why SNRs seem to be so rare.

The researchers believe this new image shows 20 possible SNRs, a huge boost to the number already known.

SNRs are giant clouds of dust and gas created from a supernova. The resulting nebula are beautiful, and relatively short lived – a few tens of thousands of years.

But models predict that, due to the age and density of the Milky Way, we should see the remnants of many, many stars that have lived and died. Instead, we only know of 30 or so in the Milky Way, the Large and Small Magellanic Clouds and Andromeda Galaxy.

"It's not totally clear why SNRs are hard to find," says Macquarie University astronomer Professor Andrew Hopkins.

"Some of it is just a sensitivity issue and needing more sensitive observations to pick up the faintest things. But another part is that they not only become fainter but also larger as they age, which makes them very dim and diffuse."

Hopkins is the lead scientist on ASKAP's Evolutionary Map of the Universe (EMU) project, which published details on a pilot survey in 2021. A paper on this new image and any SNR candidates has not yet been finalised.

▲ Combined images from the ASKAP and Parkes radio telescopes.

The researchers used the Parkes and ASKAP telescopes because of their differing resolutions. With a 64-metre dish, Parkes is one of the largest single dish radio telescopes in the world. However, ASKAP is an interferometer telescope, which uses multiple telescopes placed very far apart to mimic a single telescope with a six-kilometre-wide dish.

"However, since even with 36 dishes we can't sample all the light falling on that 6km aperture, the ASKAP image is not sensitive to the large-scale radio emission that Parkes does detect," Hopkins says.

"Combining the information ... gives us the best of both worlds – ASKAP's fine resolution together with the large-scale emission from Parkes, each filling in the gaps of the other, to give us the best fidelity image of our Milky Way Galaxy."

R. KOTHES (NRC) AND THE PEGASUS TEAM

Focus: James Webb telescope

1 **Announced last November, a fiery, hourglass-shaped stellar nursery named L1527 (shown here) has a protostar at its neck – a developing star just 100,000 years old.**

2 In December, JWST scientists confirm finding the most distant galaxy to date: JADES-GS-z13-0 dates back to 325 million years after the Big Bang.

3 **Barred galaxies EGS-23205 and EGS-24268, revealed in January, resemble the Milky Way – but come from a time when the universe was only a quarter of its current age.**

4 In January, JWST's first found exoplanet debuts. The rocky planet LHS 475b is about 1% smaller in diameter than Earth; it's orbiting a star in the Octans constellation, 41 light years away.

5 After detecting CO_2 in planet WASP-39b's atmosphere in August, JWST found SO_2 and CO in November. WASP-39b might be the best explored planet outside the Solar System.

6 **In February, JWST finds water ice in the rings of a distant object in our solar system – not Saturn, but the asteroid Charliko.**

7 Published in *Science* in February, JWST's discovery of massive, ancient galaxies has confounded science. The six 12-billion-year-old galaxies are too big to make sense of our current understanding of the universe.

www.cosmosmagazine.com/space/ 01 webb-protostar-hourglass 02 furthest-galaxy-james-webb 03 trans-differentiation-barred-galaxies 04 new-exoplanets-nasa-satellites-jwst 05 jwst-sulphur-dioxide-wasp-39b-atmosphere 06 webb-asteroid-rings-water 07 massive-young-galaxies

NASA, ESA, CSA, AND STSCI, J. DEPASQUALE (STSCI)

DISCOVERY

You can probably pick swearing in a foreign language

Ever heard a phrase in a language you don't speak and had a feeling it was offensive? Or heard a made-up swear word that doesn't really sound like an oath?

According to a new paper in *Psychonomic Bulletin & Review*, sounds in swear words can translate across languages.

Specifically, the researchers found that swear words in various unrelated languages were more likely to lack sounds like l, r, w and y: a class of sounds known as "approximants".

The researchers conducted three online studies to see whether there were universal patterns in swearing.

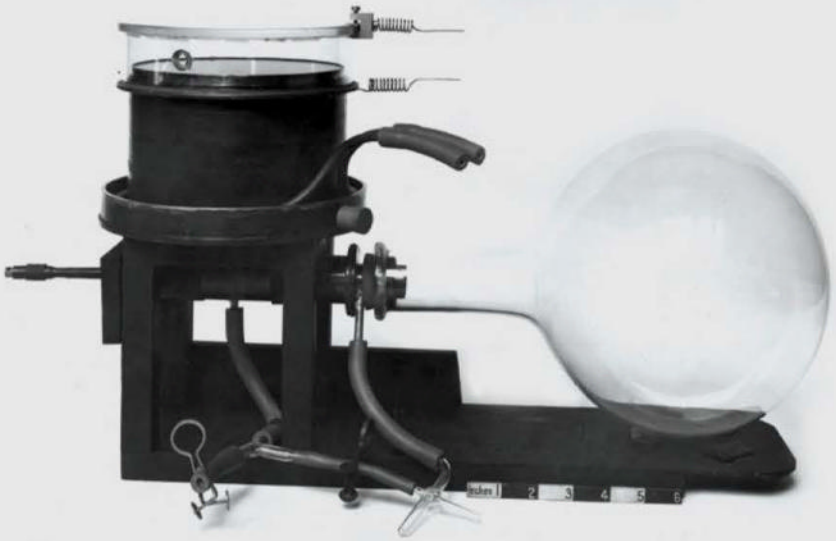
When they went looking for patterns in the resulting word list, the most promising they found was that swear words in many languages tended to avoid approximants.

"Our experiment shows that people perceive approximants to be less suitable for swear words regardless of their native language," says lead author Dr Shiri Lev-Ari, a psychology lecturer at the University of London, UK.

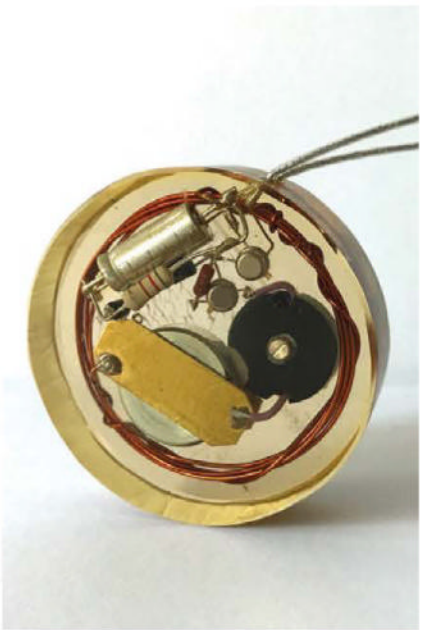
Guess the object

Sky portal

Another suggestion from a reader – thanks Matt! – this illuminating contraption played a stellar role in scientific discovery for a number of decades, including contributing to the results of more than one Nobel-Prize winning research effort. It's largely been superseded today, but is still held in esteem, as evident by the number of its various developments and incarnations kept in science institutions in various parts of the world.



We know you can Google it, but where's the fun in that? Tell us what you think it is. The correct answer – and/or the most creative – will be published in our next issue. Send your hunches to contribute@cosmosmagazine.com



Small and mighty

Last issue's object is an early artificial cardiac pacemaker, of the sort first fitted in 1958 to 43-year-old Swedish man Arne Larsson. To put it indelicately, Larsson was stuffed. His heart was so weak he had to be revived after losing consciousness 20-30 times a day. His wife Else-Marie heard about the development of this device... and the rest is history. Larsson lived to be 86, using 26 pacemakers along the way. He outlived Rune Elmqvist, who made this device. John de Vry nailed it: "[It's] an early pacemaker to regulate the heartbeat. I own an early model from the late '70s." Honourable mention to like-minded Eloise Greenland ("an electronic hearing aid") and Johnson Lai ("a 'wireless earbud', likely to be the first ever version in the '70s, for spy use etc").

FROM TOP: EPOXYDUDE / GETTY IMAGES. BROOKHAVEN NATIONAL LABORATORY. AGENT GALLERY CHICAGO

The golden spike marking the Ediacaran period at Enorama Creek, in the Flinders Ranges, South Australia.

GEOLOGY

A second golden spike?

Which point in the world best describes human history?

AN INTERNATIONAL GROUP of geologists is on the cusp of deciding how to literally mark the times we're living in.

In 2009, geologists formed the Anthropocene Working Group, to define our current geological epoch.

They asked if we're still in the Holocene, which began around 11,000 years ago, or if human activity has so dramatically changed the planet's geology that it needs a new boundary. The term 'anthropocene', from Ancient Greek anthropo ("human"), was coined by Paul Crutzen and Eugene Stoermer in 2000 to illustrate this idea.

In May 2019, the AWG agreed to listing the Anthropocene as a "formal chrono-stratigraphic unit": that is, an official part of the geographic record. They recognised the start of the Anthropocene as the middle of the 20th century.

Next in the working group's line of site is a Global Boundary Stratotype Section and Point, or GSSP.

GSSPs are markers that define the boundaries of geologic stages. They're noted in specific locations around the world by "golden spikes", which note which geologic era the site emerged.

Of the current 80 golden spikes, just one is in the Southern Hemisphere. It marks the Ediacaran period, and was featured in Lauren Fuge's Bragg Prize-winning story in Issue 91.

The Ediacaran period, from around 635 to 540 million years ago, is the final part of the Proterozoic eon, when multicellular life first emerged.

The AWG is currently deciding where the Anthropocene golden spike should be. The working group has narrowed down a list of nine possible locations, one of which is in Australia: Flinders Reef, off the coast of south-east Queensland. It's been proposed because corals have annual growth bands that reflect their surrounding environment. At Flinders Reef, the markers in these growth bands can be traced back to the 1700s.

A comparison of each site, as well as three sites that have so far been ruled out, was published in *Science* by the chair and secretary of the Anthropocene Working Group.

NATURE

Extinct giant wombat over twice the size of modern wombats

PALAEONTOLOGISTS HAVE found Australia's true giant wombat.

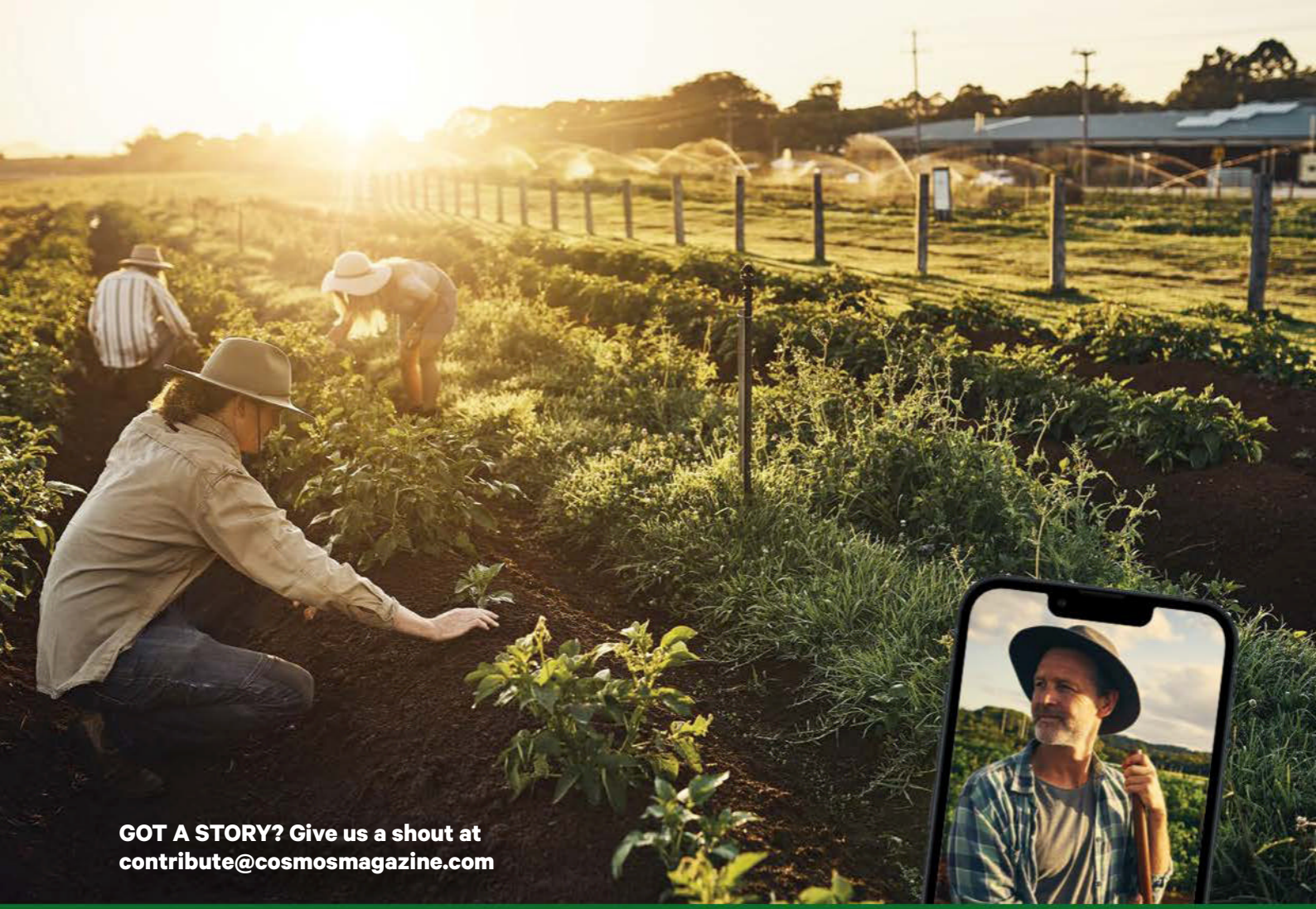
The extinct megafauna species Diprotodon is often referred to as Australia's 'giant wombat'. While Diprotodon were the largest marsupials of all time, but were only distantly related to wombats – actually a completely different family.

Now Griffith University researchers have shed light on a large species that does belong to the modern wombat family.

The fossil skull was found in a cave in Rockhampton, Qld, and is estimated to be about 80,000 years old. The species' description has been published in *Papers in Paleontology*.

Griffith associate professor Julien Louys explains that *Ramsayia magna*, which lived in Australia during the late Pleistocene (about 2.5 million to 11,700 years ago) was a true giant wombat. "We ... dated this species as being about 80,000 years old [but] we still don't know exactly when or why [it] became extinct."

ROYAL GEOLOGICAL SOCIETY OF AUSTRALIA



We're proud to have started publishing stories in our Greenlight Project: a year-long look at how regional Australia is dealing with climate change. People living and working outside Australia's cities faces huge risks and equally huge opportunities through the challenges posed by moving to a low-emissions future. How will they fare?

Our dedicated Greenlight team is going bush, to tell stories from across the nation about the people, places and industries working towards that future: facing climatic change and innovating to confront it.

Please join us – there's much to learn.
cosmosmagazine.com/Greenlight-Project

Greenlight PROJECT
SUPPORTED BY THE WALKLEY FOUNDATION AND META

Inflamed passions

By unlocking the secrets of cell death, we hope to discover the keys to a whole new realm of precision medicine therapeutics.

By Georgia Atkin-Smith

Australian scientists have long been world leaders in the field of cell death research.

Back in 1972, Australian pathologist John Kerr first described how cells undergo apoptosis – the normal, controlled death of cells that occurs as a natural part of growth. Since then, we've made many significant advances in our understanding. For example, we now know there are more than 12 different ways that cells can die.

At the Walter and Eliza Hall Institute of Medical Research (WEHI) in Melbourne, I'm surrounded by world-leading researchers who have shaped our understanding and discovered the very complex regulation underpinning cell death and survival.

We have approximately 23 trillion cells in our body and it's very important that they die, but at the right time.

Cell death removes old, damaged, infectious or cancerous cells – essentially, getting rid of the bad and making space for the good. It's pretty amazing to think that humans are just trillions of cells that have come together. That's why it's so important to understand the basic cellular biology of who we are.

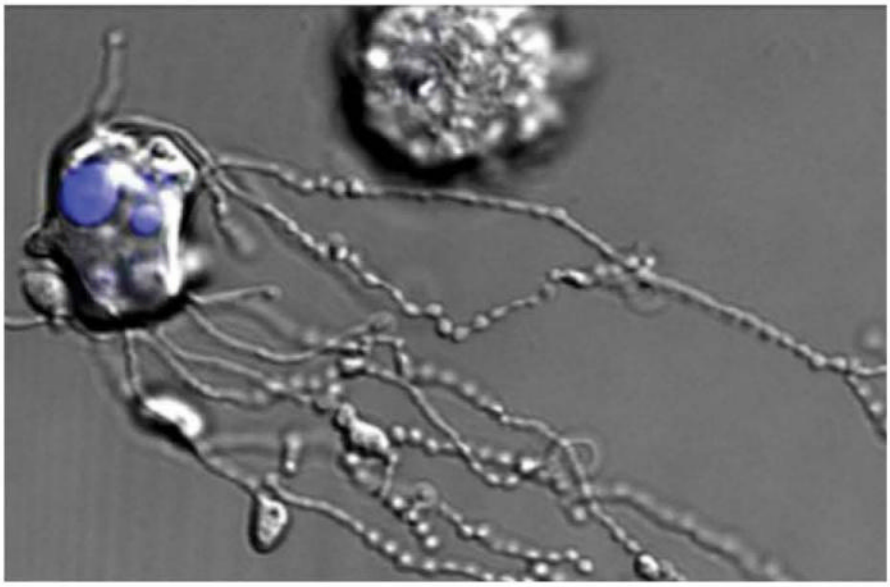
It's sometimes a struggle in research to get recognition from the broader population: a lot of people want to know about the "sexy science", such as therapeutics and translational work that's directly going into the clinic. However, researchers who work on the basic biology of science to gain the fundamental understanding underpin those advances – which allow us to translate these findings into the clinic and create an impact.

We have learnt so much over the past 50 years, but there's still so much we don't know, and some of the biggest challenges are in the cancer field.

If we're going to kill a cancer, the best way is to do it in a way that's selective. If we can have a better understanding of how our cells are dying, and if it's good or bad in a particular setting, it's going to be a very exciting area for us to expand on to make more directed therapeutics. We're eventually going to be looking at the genomic details of each individual to match it against the effectiveness of particular therapies. This realm of precision medicine is definitely the next big thing.

That's why it's so important to have places like WEHI spreading their research

LA TROBE UNIVERSITY



Left: In 2015, Atkin-Smith co-led the team that captured on video each stage of the death of a human white blood cell – for which she was awarded the People's Choice award at the Victorian Young Achiever Awards the following year as a PhD candidate.

across a wide variety of diseases, with different bodies of researchers working in different areas.

My particular area of research looks at how dying cells can cause inflammation. Inflammation is a process that's involved in many diseases; whether it's arthritis, cancer or autoimmune diseases, it has implications in many settings.

People might think of inflammation as the red swelling you see on your skin if you have an insect bite or a cut or a graze. And it's normally a good response that your body has to ring the alarm bells, essentially bringing all the good cells to the site to help fight that danger. But it all comes back to a balance. When our cells die too much, they become the garbage of the body and can trigger harmful inflammation and drive diseases like arthritis.

My focus is on understanding how these dying cells are removed to prevent inflammation. If they linger too long, dying cells can burst like a balloon, releasing pro-inflammatory factors that recruit immune cells. This can overwhelm the area, drive inflammation and turn pathogenic. My research (supported by the L'Oréal-UNESCO For Women In Science Fellowship) will allow me to set up new, exciting projects, including a model of bacterial infection.

Our team will look at a model of salmonella, which many of us know as a stomach bug that can make us sick. You may not know that salmonella can kill our cells during infection. We want to understand this infection-induced cell death: how these dying cells are removed and – importantly – how we can resolve inflammation during infection.

> “If we're going to kill a cancer, we have to do it in a way that's selective... this realm of precision medicine is definitely the next big thing.

It's incredible to work at a research institution like WEHI, because the collaboration opportunities are endless.

In addition to internal collaborations, the Peter Doherty Institute for Infection and Immunity is located across the road, plus the Peter MacCallum Cancer Centre, the University of Melbourne and many hospitals are all within the same precinct, promoting incredible collaboration opportunities across a broad range of diseases – Parkville certainly is a leading hub for medical research!

However, there are of course many incredible researchers located across the country and the globe that would immensely benefit from staying connected and collaborating. Therefore, this was my lockdown project: some people made sourdough – I founded the Australasian Cell Death Society (ACDS), an international society for Australasian cell death researchers.

The ACDS has been really well received and we now have over 300 members who come together for online forums and monthly seminars.

We also have a newsletter, support our junior researchers through awards, professional development workshops, and we're holding a conference in 2023. We're providing many opportunities to communicate within the scientific community, but also to collaborate.

Who knows what we might discover if we all put our heads together and support each other's research?

DR GEORGIA ATKIN-SMITH is a cell biologist at the Walter and Eliza Hall Institute of Medical Research.

LA TROBE UNIVERSITY

Cool fire: unlocking old burning secrets

Sediment core samples paint a picture of the healthy relationship between humans, vegetation and fire across millennia in Australia.

By Michael-Shawn Fletcher

I t's field-based research that I love. Getting out on Country. My parents used to remark that as a kid no toy of mine ever lasted a week before I'd be pulling it apart and trying to put it back together. I just love knowing how things work, and that extends into the world around us – trying to understand how our environments work, and what the dynamics are.

My coring devices are personal designs that I've hodge-podged together from different equipment. If you're working in a lake, you'll need a drilling rig that can handle the sloppy sediments, but also retrieve a column of sediment from the bottom of the lake, and

MICHAEL-SHAWN FLETCHER

these can be 50–100 metres deep. Or if you're on a bog, you'll need something that you can operate handheld to push down into the peat and slice out sections. It's also got to weigh under 400 kilograms so that the lightest range helicopter can move it.

Once you've managed to get out an undisturbed column of sediment, you then need to package the material up and return it to the laboratory. We mostly put samples into polycarbonate tubing, which we split longitudinally back in the lab to give us a perfectly straight surface. We then take our cores to ANSTO – the Australian Nuclear Science and Technology Organisation – for scanning.

There we use a micro X-ray fluorescence scanner, which shines a molybdenum-powered light source onto the sediment surface, which excites the atoms. They begin to vibrate and re-emit energy, and the re-emission wavelength is dependent on the atomic number. You get an elemental profile every 100 microns down your sedimentary sequence. This can tell you all sorts of things.

The other half we slice in five millimetre increments, sometimes even finer, and use chemical washes to isolate certain fractions, which we call proxies. A proxy is simply something that stands in substitute for something else, so pollen traces, for example, is an indicator of vegetation, charcoal is an indicator of fire, diatoms are an indicator of water quality or water dynamics. Whatever your interest is, there's a large array of proxies you can isolate within each segment.

Pollen is extracted and counted under a high-powered microscope. You then marry that with your charcoal contents, and with each of those little slices you can start to understand fire-driven vegetation change.

The last Ice Age fully ended 11,900 years ago, when we entered the Holocene – a geological epoch where climate has been variable and dynamic, but relatively stable on a global geological scale. That was a huge reorganisation that drove massive changes in global vegetation. The years since then have been marked by a lot of relatively small-scale events – until contemporary climate change.

But since that exit from the Ice Age, the single biggest event we see right across south-east Australia has been the removal of Aboriginal management of the land following the British arrival. The biggest and most ubiquitous shift has clearly been the cessation of cultural burning.

We see fuel loads increase as trees and shrubs increase in density. That causes the onset of bigger and more severe fires. Geochemical data tells us we're seeing a lot of post-fire erosion that wasn't there before.

This is forensic work – there were a lot of unknowns that we had to triangulate with lots of other lines of evidence to reduce the range of explanations to account for those co-occurrences. But this allows us to test the difference between cultural burning (cool burning) versus catastrophic bushfires, which are very hot burning. It's going to empower us to start asking critical questions about the temperature of fires Aboriginal people were using to maintain the biodiversity we're now losing at a rate of knots.

Importantly, this information helps us to understand that the concept of "wilderness", as we've come to know it, is a myth. Full stop. Work being produced here and overseas shows that less than 20% of terrestrial Earth, including areas of ice, has been unaltered for the last 12,000 years. Since the last Ice Age, humans have had a profound influence on global dynamics. This has now been quantified to show that the vast majority of the Earth has been altered by humans in some way. This concept of "wilderness" is very much a cultural one, with British origins.

What we see from our work is that there are very few, if any, parts of Australia that could be called wilderness. Sure, there are rainforest pockets – Aboriginal people didn't burn every inch of the continent, but worked to protect some areas and manage others. This modern notion of wilderness denies the management of Country by Aboriginal custodians for all those thousands of years. And as we are seeing, if we remove that Aboriginal management, ecosystems collapse.

There's a growing realisation that we need this Aboriginal knowledge and information if we are to operate sustainably on Country – that this ancient know-how needs to be reawakened.

Science has a role in backing up and supporting traditional knowledge, filling in gaps where there may be some. But the next big thing we can do is actually sit down and give people the space and confidence to share their knowledge and be happy for that to be used in ways to heal Country.

> There are very few, if any, parts of Australia that could be called wilderness.

From far left: Burning country in East Arnhem Land during a University of Melbourne field trip; the author extracts a core from the Bolin Bolin Billabong in Bulleen, Victoria

MICHAEL-SHAWN FLETCHER is a Wiradjuri scholar and Associate Professor in Geography, Earth and Atmospheric Sciences at the University of Melbourne.

AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION

FINDING ALIEN LIFE IN OUR SOLAR SYSTEM

Forget the Martian thing: alien life is possible in our solar system, and future space probes might confirm it, writes **Sara Webb**.

Are we alone in the universe? It's one of the most intriguing questions in science, because there are only two possibilities, Yes or No, and either is equally exciting and terrifying.

The bounds of our astronomical knowledge have expanded exponentially in the past 100 years; our observable universe is suddenly bigger than we can comprehend. With trillions of galaxies and quadrillions of stars, it seems impossible that we'd be the only living things within this vast universe, and the only way to know for sure is for us to look.

The easiest place for us to really investigate first-hand the possibility of alien life, is in our very own cosmic backyard, the solar system. Our solar system is home to some pretty remarkable places, many with the potential for life as we know it.

Before we dive into where we should be looking and why, let's first define what life needs to survive.

All life on Earth is something called "carbon based". Our DNA, tissues, proteins, fats and almost everything else in living cells are built around carbon. Carbon allows up to four different and simultaneous bonds between it and other atoms, making it incredibly good at forming long chains of molecules, like the ones that form our DNA.

One of the most important things carbon-based life needs to survive is water. Water is used by our cells to facilitate chemical reactions. So when we're searching our solar system we're looking for hints of organic carbon-based matter, and for water.

Only in very recent times have we discovered or confirmed the existence of water in our solar system beyond Earth. Places like the Moon and Mars appear to have pockets of frozen water at their poles, but these are not the places we're excited about.

It was the 2005 discovery of liquid water spewing out of Saturn's icy moon Enceladus that changed everything. The images sent back from the Cassini space probe were mesmerising. They showed an alien moon with huge geysers of liquid water flowing out of the surface. It only got better when plumes of water were finally confirmed in 2018 on Europa, the icy moon of Jupiter.

We believe that both of these moons harbour massive amounts of liquid water, in under-surface oceans that could have friendly conditions for life to form. The frozen ice crust of each moon is thick enough to provide protection from harmful radiation. The building blocks of DNA are amino acids, organic compounds that can be destroyed if exposed to radiation over long periods of time. The water on each moon likely contains important ingredients for life – such as salt, carbon, hydrogen and sulphur – and on Enceladus we've even found organic compounds in the escaped water.

> "THEY SHOWED AN ALIEN MOON WITH HUGE AMOUNTS OF LIQUID WATER FLOWING OUT OF THE SURFACE.

The Juno spacecraft's September 2022 images of Europa (above) were taken from just 400km above the Jovian moon's surface. They're the highest-resolution close-ups of Europa captured to date. In 2005, the Cassini probe's flyby of Saturn's moon Enceladus (opposite) provided evidence of liquid water: a game-changer in the search for possible alien life in our solar system.

So with two excellent locations to look for life, where do we focus our attention?

NASA's answer is Europa. (Don't worry, I'm sure we'll be back examining Enceladus one day.) One of the main reasons Europa is a great first candidate is because we are currently already there.

The Juno spacecraft has been orbiting the Jovian giant since 2016, investigating both Jupiter and its orbiting moons. The images and science we've received from this mission are astounding; we now have a better understanding of Jupiter's storms, changing magnetic field and auras, and the highest resolution images of Europa we've ever seen.

Just in September 2022, Juno dipped down to only 400 kilometres above the surface and took breathtaking images that provide us with the information we need to plan a detailed probing mission.

NASA is currently developing the Europa Clipper mission, designed to perform several close flybys,

NASA/JPL/SPACE SCIENCE INSTITUTE

using speciality scientific equipment to scope out the surface like never before. The main science objectives of this program are first, to determine the thickness of Europa's outer icy shell and how this changes over the surface; second, to scope the composition of Europa's under-surface ocean and learn if it has all the key ingredients to support life; and third to characterise Europa's geology, to identify the most likely places for life to exist – information to inform future investigations and missions.

We've been exploring our solar system via rovers and probes for more than 50 years, and in the next 10–20 we're expecting to get closer than ever to answering "is there life out there?". Missions like Europa Clipper will provide us with the most detailed data about just one of the places we might find life, but we'll have to be patient. Currently under development, the mission's expected to launch in 2024, and arrive at the big friendly giant Jupiter in 2030.

> "THE SAME AS ENCELADUS AND EUROPA, WE SUSPECT TITAN IS HOME TO A SUB-SURFACE OCEAN.

Good things always come to those who wait, and the 2030s will see more missions to get excited about.

In 2034, the Dragonfly mission is expected to reach Saturn's moon Titan. Titan is unlike any other moon in our solar system, because it's home to a dense atmosphere and surface lakes. The same as Enceladus and Europa, we suspect Titan is home to a sub-surface ocean. Titan's nitrogen-rich atmosphere is thicker than Earth's, and we've previously

WHAT MIGHT IT LOOK LIKE?

The Dragonfly mission will be heading into the depths of the very alien world of Titan, one us earthlings can barely imagine. So, what would life look like living in lakes of methane, or breathing in nitrogen?

We have two theories. One is that life might be like extremophile organisms here on Earth; and two is that it may be completely unlike anything we've even seen before. Both possibilities are incredibly exciting.

We've found extremophiles here on Earth in some unlikely places, including 6.7km inside Earth's crust, 10km deep inside oceans and incredibly, inside hydrothermal vents. We've even found certain organisms in this group that can metabolise methane, called Methanotrophs, which can be found living in terrestrial mud volcanoes. Organisms like these teach us that life on Earth is persistent, and found in places we once thought would be uninhabitable.

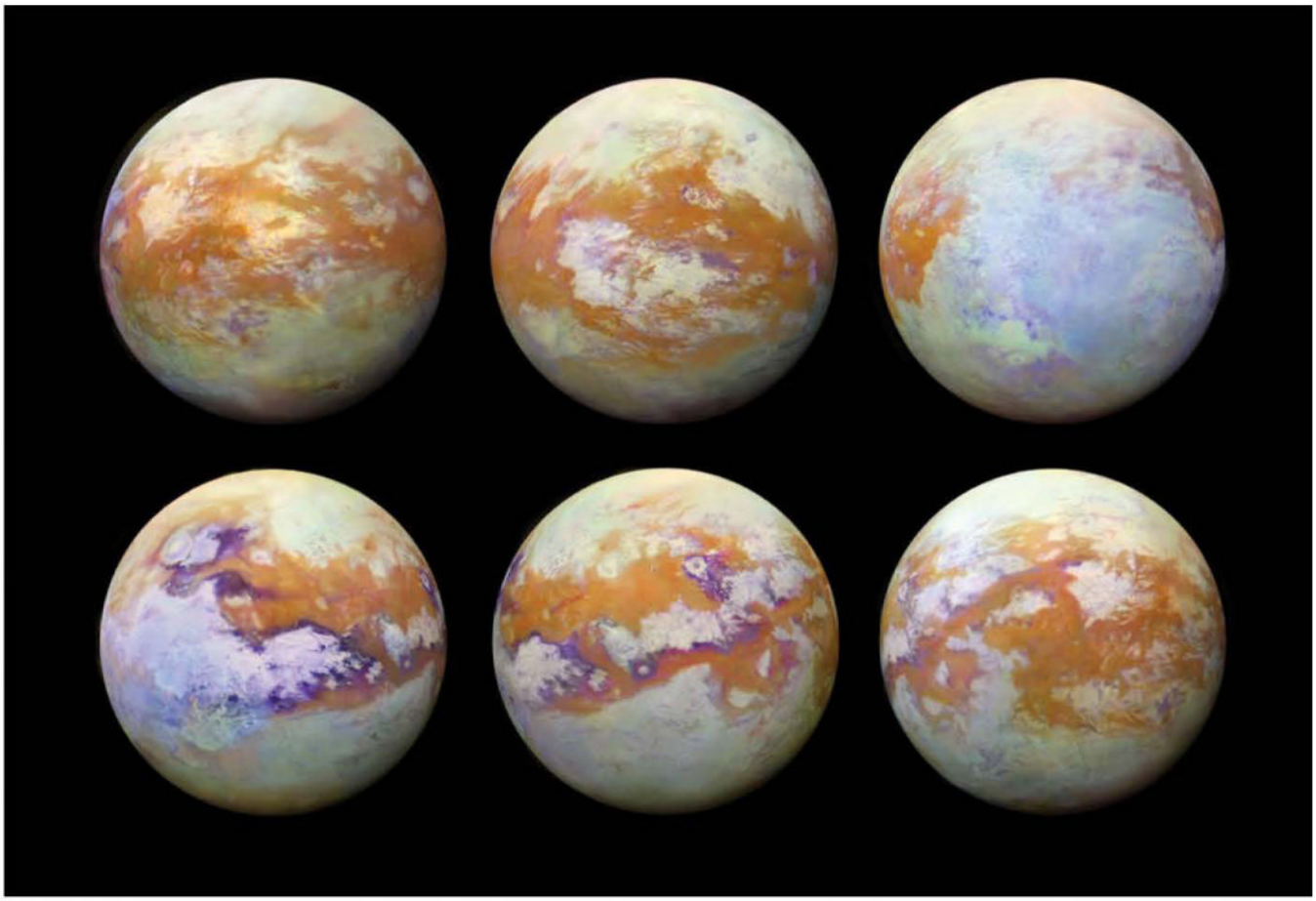
In my opinion extremophiles give us the greatest hope when it comes to finding alien life in our Solar System – which is both cool and a little underwhelming. It may be that alien life is visible only under a microscope – huh, and wow! Extremophiles on Earth are some of the most interesting creatures I've ever seen.

One of the best examples is the beloved tardigrade or water bear. These tiny creatures – just 1mm in length – can survive very harsh environments. Their signature bear appearance comes from their six leg-like appendages, each with claws attached. As remarkable as these creatures are – and we suspect they could, in theory, survive on other celestial bodies – we don't think they would survive on Titan's surface. So, what other organisms could, and how would they have evolved in this environment?

One of the most common theories is that Titan life might be completely different to anything we've found on Earth and could have evolved in the hydrocarbon lakes: which brings us to a second theory.

Life on Titan could be unlike anything we've even seen before, and possibly not even carbon based. Researchers have speculated that silicon-based life might be suitable for a Titan-like environment, where a completely different type of biochemistry would be needed to survive in the methane lakes. Titan's surface has very low temperatures and severely lacks the oxygen and liquid water that carbon-based life needs to survive. In theory, silicon-based life would look very different to us – how different is hard to say. We haven't found or created silicon-based life here on Earth and it's unlikely we'll find it on Titan either. Early estimates suggest there might be too little silicon on Titan's surface, with most likely locked up deep in the interior. But until we explore this mysterious moon, we won't know what might be living on the surface.

STEVE GSCHMEISSNER/SCIENCE PHOTO LIBRARY/GETTY



NASA/JPL-CALTECH/ STÉPHANE LE MOUÉLIC, UNIVERSITY OF NANTES, VIRGINIA PASEK, UNIVERSITY OF ARIZONA

These infrared images (above) of Saturn's moon Titan represent some of the clearest global views of the icy moon's surface produced so far. The images were assembled from 13 years of data acquired by NASA's Cassini spacecraft.

identified complex organic chemicals and hydrocarbons within it. This unique atmosphere has intrigued astronomers ever since its discovery and we're still trying to understand it with our best telescopes.

In December 2022 the James Webb Space Telescope teamed up with the Keck Observatory on Earth to image and track the movements of clouds around Titan. This new data made me stop in my tracks because for the first time, I saw a pale blue dot in space that wasn't the Earth. Titan suddenly didn't seem so alien, with its hues of blue and green, and visible clouds. These observations have confirmed long-held modelling theories that clouds should be able to form in its northern hemisphere. We're still investigating what this new data means, but we're closer to understanding this amazing little world.

Titan is also an intriguing place thanks to its surface lakes of liquid methane. Some scientists hypothesise that life could possibly exist in these lakes, inhaling hydrogen-2 instead of oxygen, and exhaling methane instead of carbon dioxide. We've never found life like this on Earth, but on this alien moon, the mechanisms for the formation and evolution of life might just be entirely different.

The only way for us to really know for sure is to investigate it with probes. The Dragonfly mission will drop a large drone down into Titan's atmosphere and study in-situ how far prebiotic chemistry might have progressed there. Another exciting mission that hopes to push humanity closer to understanding how likely life is elsewhere in the solar system.

Each of these missions will no doubt provide us with greater understanding of these extreme and unique environments like never before, and possibly close the case of "are we alone?" in the universe.

SARA WEBB is an astrophysicist at Swinburne University of Technology. Her last story – on JWST – was in Issue 96.

WHAT ABOUT LIFE IN THE GREAT BEYOND?

Our Solar System might not be hiding little green men for us to find, but that doesn't mean they aren't out there, somewhere.

Our universe is unimaginably big. With over two trillion galaxies in our observable universe, it's unlikely that we're the only beings. In our galaxy alone we have over 400 billion stars and likely, many more planets. If life could form like it has here on Earth, statistically across the universe, it should be able to form again and again. The problem we face is confirming if this is true, and this is where us astronomers start to talk a lot about the Fermi paradox. The big question famously asked by Fermi was "where is everybody?". The answer is we don't know, but we can't rule out that, somewhere, there are other beings like us, asking the exact same question.

Seeing emotions

Brain-machine interfaces and emotional AI are real enough to be undergoing trials. **Petra Stock** considers what they mean for the future – and whether they're needed at all.

What if technology could tap into a raw data feed of your feelings and manifest them in a kind of digital aura? If anger and annoyance agitated as red asymmetric fractals; or peace and calm floated by in blue, infinite loops?

That possibility is here in a device that looks like a 1960s swimming cap worn with ski goggles. Called Neo-Noumena, it's designed to "read" its wearer's emotions, representing them as a digital halo of spirographic shapes.

"Neo-Noumena was an attempt to expand how much information people can pass to each other in communicating about their emotions," says its creator, neurotechnologist Dr Nathan Semertzidis.

Since he was little, Semertzidis has been enthralled by bionics – the use of technologies to extend the human body and mind. His interest is partly informed by personal experience – he has a genetic hearing loss and wears hearing aids – along with a childhood fascination for science fiction.

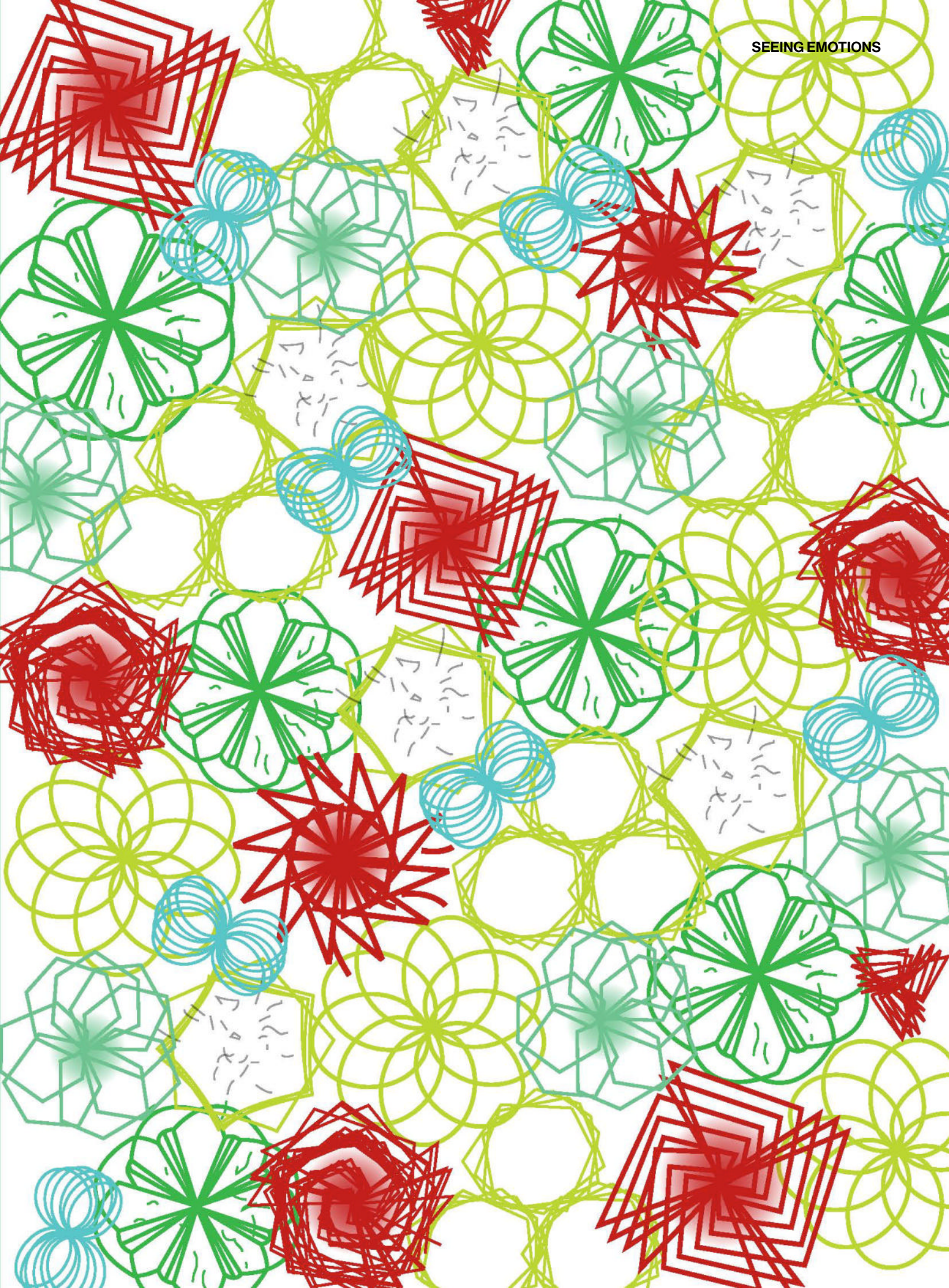
"I wanted to work on technologies that interface the human brain with computers, to exchange information between the two, and to further that dream of becoming a cyborg that I had when I was a kid," he says.

Music makers, dreamers of dreams

Semertzidis configured Neo-Noumena at the Wonka-esque Exertion Games Lab, where he works as a research fellow. Ensconced in Monash University's Clayton campus in Melbourne's south-east, the lab's bright and airy warehouse contains all manner of contraptions and gadgets. There's a bouldering wall that can tilt based on a climber's breathing patterns, banana-yellow high jump mats, a crate of pool noodles and a floatation tank, along with a series of outlandish-looking electrode hats and augmented and virtual reality (VR) glasses.

Play and experimentation underpins the research philosophy here, as a dozen or so researchers tinker with futuristic technologies that can interface directly with the human brain or body. The goal they're working towards is a singular human-computer entity.

Semertzidis' retro-futuristic headset is one of a set of brain-computer interfaces he's designed. There's also Inter-Dream, a VR system to facilitate sleepiness; and PsiNet, a kind of 'hive mind' designed to amplify shared brain activity in couples or groups.



Neo-Noumena's high-tech headgear is made from three pieces of kit.

First, a mobile electroencephalogram (EEG) device monitors brain activity via a series of black electrodes polka-dotted over the white mesh skull cap. The headset tracks electrical activity in the brain, data which previous studies have correlated with emotional states.

EEG is not a new technology. It's been used as a diagnostic tool in neuroscience and psychiatry for decades. But recent years have seen the hardware become more affordable and widely accessible through initiatives like OpenBCI. These days anyone can pick up a neurotechnologist's starter kit for the price of an iPhone and even run it on open-source software.

An artificial intelligence (AI) system sorts the filtered EEG data into four distinct emotional states, based on whether an emotion is positive or negative (classified as high or low valence) and the degree of energy or arousal.

Augmented reality (AR) technology is what makes these states visible, making emotions appear as swarms of geometric shapes, fractals circling within 1.2 metres of the wearer when viewed through the HoloLens goggles.

Shapes are displayed as symmetrical and curved for a positive emotion, or bent out of shape for a negative one. They might move fast or slow depending on the level of energy behind the emotion. Happy or excited feelings – high arousal, high valence – might show up as speedy green spirals. Their counterpoint, bored or sad states, are slow, misshapen yellow objects.

"It's kind of like having a swarm of bees or a flock of birds flying around you," Semertzidis says.

Out of the lab and into the wild

Semertzidis' research involves prototyping, testing and then analysing the use of these brain-computer interfaces "in the wild". That means taking Neo-Noumena outside the lab and into people's homes and everyday settings.

Ten participants – five pairs made up of four couples and a mother-son team – took the devices home to try them out.

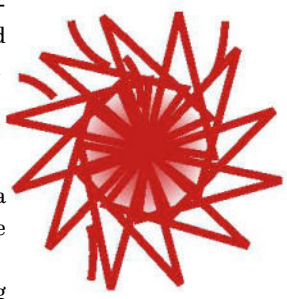
They donned the cap and goggles in a variety of situations – when they got home from work, completed assignments, watched comedy, played card games, listened to music or relaxed. They observed and diarised the ways the apparatus embodied their own and their partner's emotions through physical space and time.

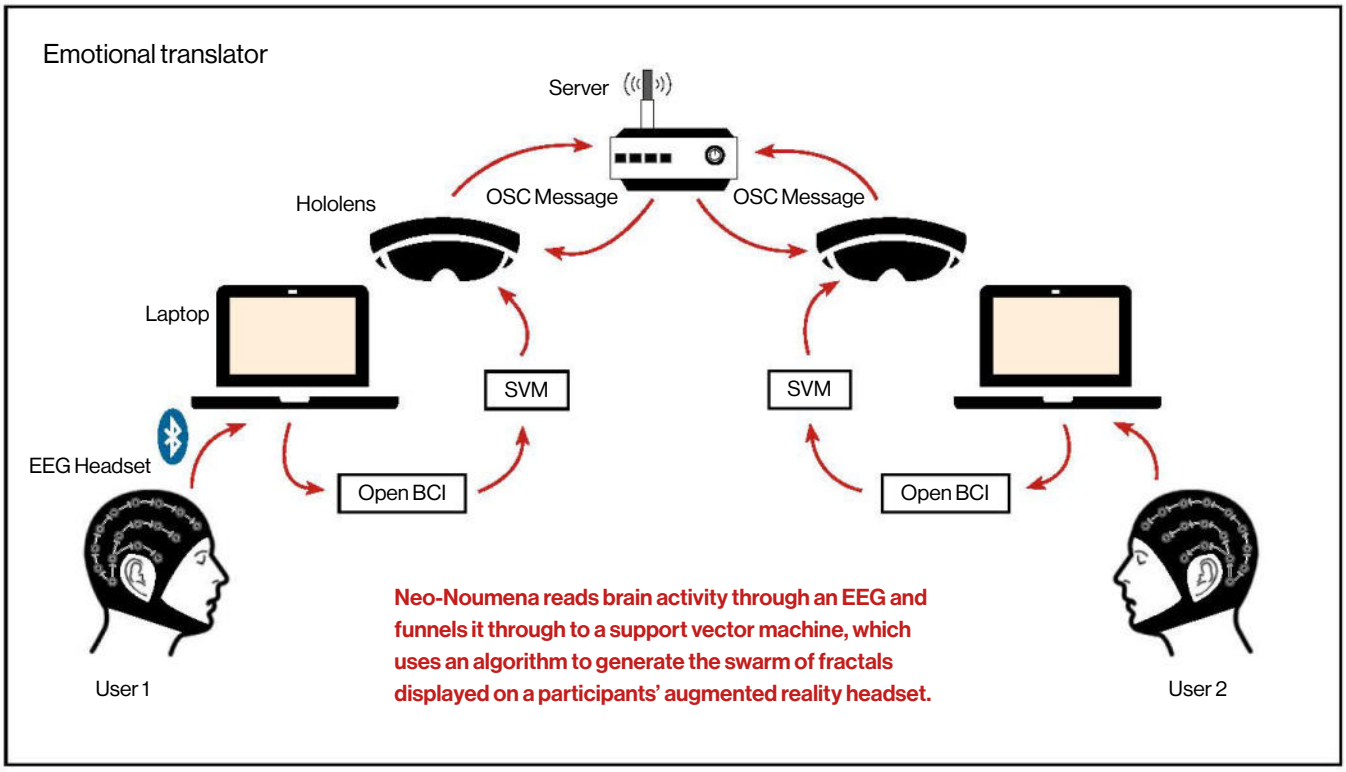
Semertzidis' 2020 paper about Neo-Noumena records the participants' responses to qualitative interviews about the experience.

One describes the experience as akin to having a pet: "It lands on your table, kind of like a cat [...] but instead of a cat, it's literally a piece of your emotion."

Many others became more acutely aware of their own emotional states and their effect on

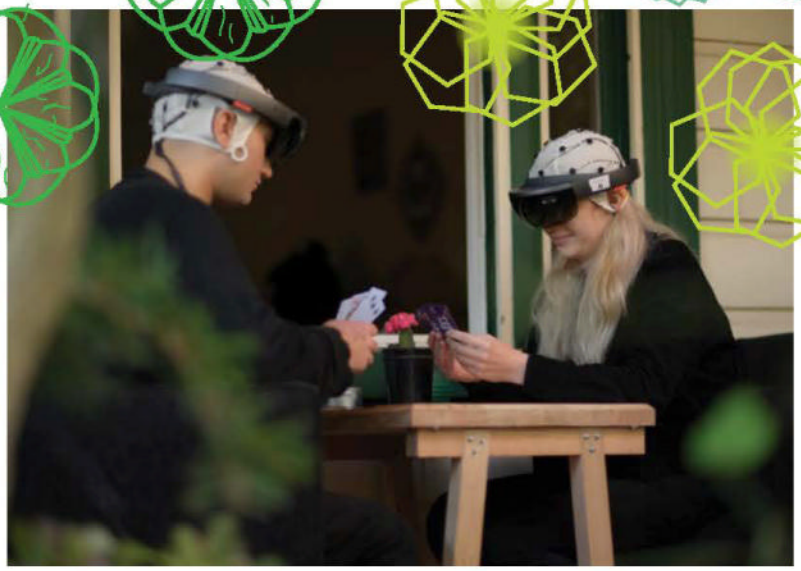
Neo-Noumena translates emotions into fractals that circle the person wearing the equipment within 1.2m. Happy or excited feelings, for instance, might display as fast-moving green spirals. All the fractals shown on these pages are shapes generated by Neo-Noumena.





Neo-Noumena reads brain activity through an EEG and funnels it through to a support vector machine, which uses an algorithm to generate the swarm of fractals displayed on a participants' augmented reality headset.

NATHAN SEMERTZIDIS X2



others. Some found it reassuring to watch their emotional states change and flow.

"It was like a constant visual reminder to consider someone's mood [...] and just appreciate that other people have emotions as well," one says.

Semertzidis says if two people are experiencing the same emotion, the fractals might even swarm together and effectively "hang out" in the middle of the room. At those times, the device seemed to intensify the pleasure of a shared emotional experience, like when two participants spent an evening drinking and listening to music.

"The whole night we were singing and dancing along with the music, and we were generating some pretty positive emotions," one recounts. "For me that made me even happier to see that she was happy. It felt like it was feeding back in on itself, like a nice big loop of happiness."

Communicating emotional experiences is core to being human, "yet also notoriously difficult", Semertzidis says. This is what Neo-Noumena seeks to address.

The question is: do we need technology's help to encode and decode human emotions?

Mixed feelings

Humans are "exquisitely good at both communicating emotions facially and reading them in others", says Nick Haslam, professor of psychology at the University of Melbourne.

"There's a very intricate orchestration of 40-odd muscles which create facial expressions of emotion. And humans are just incredibly good at decoding those things."

People can also physically express their emotions through voice tone and intonation, body movements (like slumped or expansive poses), and heart rate. And, of course, using words.

Haslam says emotions are "a connected pattern of thoughts, feelings and actions oriented towards events in the world".

"Emotions aren't just patterns of brain activation over the scalp," he says – they are inherently complex, made up of subjective feelings, thoughts, behaviours and physiology.

Haslam adds that sharing emotions has an important social role. For instance, fear communicates to others the presence of a threat to be avoided, whereas "anger can have a function of expressing authority, expressing moral disapproval of someone else".

Indeed, a study by Belgian psychologist Professor Bernard Rimé found that emotions are mainly social, as opposed to private and individual. Rimé found that up to 96% of experiences are shared with others.

To complicate matters, a person's internal emotional experience can sometimes contradict the emotion they choose to express.

"The jargon in psychology is emotion regulation, when you try to express an emotion different from the one that you're initially feeling," Haslam says. This might mean dampening down sadness or self-pity in the face of someone else's success, showing gratitude for an unwanted gift, or even overcoming an inappropriate giggle at a funeral. "To some extent the feeling part is private, unless you communicate it," he says.

People can also physically express their emotions through voice tone and intonation, body movements, heart rate and using words.

Haslam says that technologies – from text messages to Zoom calls – often get in the way of communicating emotion; they act as a barrier by removing crucial face-to-face, or in-person contact. The result is continuing efforts to create workarounds.

"The rise of emojis in texts, for instance, is largely a response – not just because they're kind of cute – it's because it often is difficult to communicate subtleties of emotions, or things like sarcasm over pure text without the usual back and fro of face-to-face contact," Haslam says.

The Neo-Noumena study suggests the system might augment people's ability to read their partner's emotions, even the private ones. One of the participant pairs played a card game while wearing their headset, and used the swirling fractals as an additional tactic for deciphering their opponent's

poker face. The fractals were "mellow if it was a good hand", and "red towards the end of a round where it's determined who is going to win or lose".

In another example, a participant was working on a university assignment while their partner was playing music. Semertzidis describes the encounter: "The one playing music was like, 'Oh, is this annoying you?'. The one doing the assignment said, 'No, it's fine.' But they saw the fractals were obviously annoyed."

"You can imagine a dystopia where a machine can detect your deepest, darkest thoughts just from looking at you," Haslam says. "But my sense is that that is so distant as a possibility, and it's so far beyond what we can currently do, that I don't worry about it too much."

Emotional AI: friend or foe?

"Some of what's going on here is a neuro-fetishism," says Monash professor Robert Sparrow. "This idea that if you can read it in the brain it's somehow more real than if you could just look at someone and see that they were sad."

Sparrow, a philosopher specialising in technologies and applied ethics, is concerned about the pervasive use of systems like facial recognition being programmed to gauge the public's emotional state. His particular worries include people's lack of choice to be monitored and the technology's potential for manipulation.

"Advertisers have been quite interested in the possibility that they might be able to spot people walking past a billboard, find their emotion, and maybe tweak their pitch, in accordance with people's emotion," he says.

"Notoriously people, as I understand it, consume more when they're feeling slightly sad. So if you can identify people when they're vulnerable and pitch your products at them, that would be a way of increasing sales."

Dynamic pricing systems could even be used to gauge someone's emotional state, with prices adjusted accordingly for maximum commercial advantage, Sparrow suggests.

The interest of enterprises has already been piqued by emotional AI technology's potential to dig into consumers' inner thoughts and feelings.

Cosmetics giant L'Oréal is partnering with technology company Emotiv using EEG devices to detect emotional responses to different scents, to "help consumers make accurate and personalised choices around their fragrance", according to a company press release. The BBC reports that music platform Spotify patented technology for analysing a user's emotional state based on speech recognition, to further personalise content recommendations.

Meanwhile consumer brands are collecting and analysing biometric and facial recognition technologies for the purposes of targeted advertising, or product development. Confectionary maker Mars partnered with technology company Affectiva to study the facial expressions and emotional responses to its advertising of more than 1,500 European participants, in the largest such study yet.

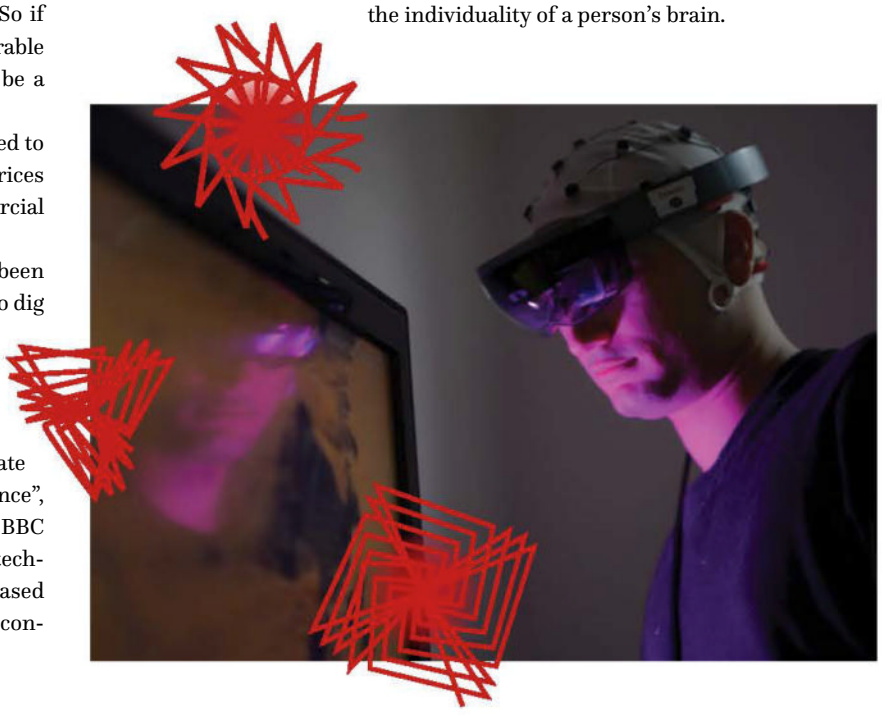
To some extent the system might be as arbitrary as a mood ring, with "a bit more information that goes into it and a bit more processing".

One Neo-Noumena user described the experience as akin to having a pet: "It lands on your table, kind of like a cat [...] but instead of a cat, it's literally a piece of your emotion."

These systems work differently but all rely on collecting personal data, tracking everything from gazes and facial movements, to walking gait, online sentiment, brain signals, heartbeats and skin moisture.

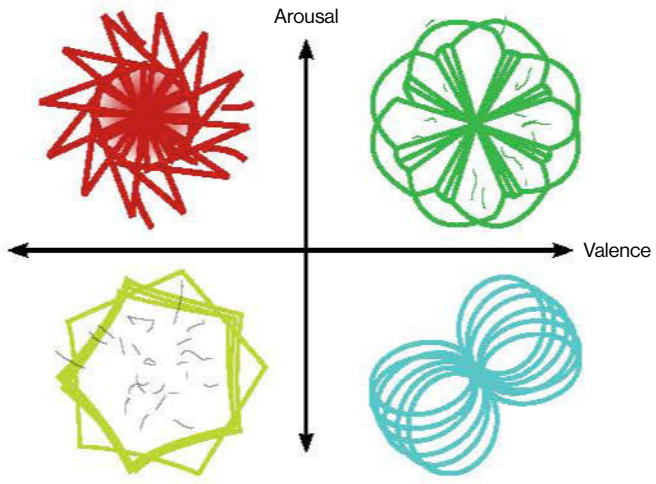
Sparrow says there are privacy concerns too. People are used to curating their digital selves in various ways, he says. But most would find it challenging to moderate their facial expressions and other emotional indicators at every point of interaction with a laptop, phone or security camera system. He wonders about the accuracy of emotion-reading brain-machine interfaces. "If someone looks happy, and they say they're happy but yet your brain reader says that they're sad [...] how do you know that the machine is not just making a mistake?"

Semertzidis agrees that at this stage EEG brain-reading systems can be inaccurate. They are based on generalised models that don't fully capture the individuality of a person's brain.



NATHAN SEMERTZIDISX2

Four types of "read" emotion



Neo-Noumena's emotions classification system currently has just four categories: high arousal/high valence, high a/low v, low a/high v and low/low, with shapes transforming between categories moment to moment. According to a 2020 research paper, the system's accuracy was 58%.

Neo-Noumena's classification accuracy was around 58%, according to the 2020 paper. To some extent the system might be as arbitrary as a mood ring, with "a bit more information that goes into it and a bit more processing", Semertzidis says.

But study participants assumed the system's output to be the objective truth. They even trusted the device at times when it diverged from their own experience or gut instinct, Semertzidis says.

"If it didn't align with how they were feeling, they felt that perhaps they were wrong, and the machine was right," he says. This highlights a danger that "people could probably put their faith in the machine over themselves".

Yays and nays

Through toying with these emerging technologies, Through engagement with these emerging technologies, Exertion Games Lab hopes to open people's minds to technologies that are just over the horizon and ways they could be used.

"This can inspire a utopian vision of the future – and also give you an idea of where things can go wrong," Semertzidis says.

A project called 'Machine in the Middle' explored the possible unintended consequences, or 'dark patterns' when brain-computer interfaces are used to classify emotions, beyond a user's agency or control. In Machine in the Middle, an EEG headset is fitted with electrical pulses capable of stimulating the wearer's facial muscles. The headset then makes their face conform to certain expressions – stressed, happy, sad, relaxed – in keeping with their internal emotional state.

Privacy and human rights watchdogs are already taking note.

The UK's Information Commissioner recently warned of the privacy and accuracy risks involved with collecting and holding vast amounts of personal biometric data.

Emotional AI is a high-risk technology that "may reveal highly sensitive data via subconscious behaviours and responses, interpreted through highly contested forms of analysis", according to a report from the commissioner's office. The report highlights specific risks relating to the use of children's data, or uses such as workforce or public surveillance.

Deputy information commissioner Stephen Bonner says biometrics and emotional AI technologies are immature and may not work. "We are concerned that incorrect analysis of data could result in assumptions and judgements about a person that are incorrect and lead to discrimination."

Leading neuroscientists are calling for 'neuro-rights' to be added to the UN's Universal Declaration of Human Rights. They are seeking to enshrine the right to identity, free will and mental privacy and guard against abuse and manipulation by emotion and brain-reading technologies. Chile's parliament has already taken steps to amend its constitution accordingly, the first country to do so.

At this stage, wearing Neo-Noumena is very much an opt-in arrangement, and one limited by the discomfort of the hardware. Participants in Semertzidis' study struggled to wear their headsets and goggles beyond the minimum hour-a-day agreed to. The cap was heavy; the goggles sometimes pinched their noses. The gel that had to be injected into the electrodes messed up their hair.

Brain-computer interfaces are very much in their infancy. But, as systems improve, they will drastically change what it means to be a human, or maybe even move beyond that, Semertzidis says.

"In the future, when we get better at connecting brains together, we might start to see things that only exist in science fiction. Like human hive minds – where our thoughts and experiences are shared between thousands of people instantaneously – and we have access to the collective information of the entire human race."

Today's emotional AI technologies are but baby steps. The interest lies in where they're leading us next.

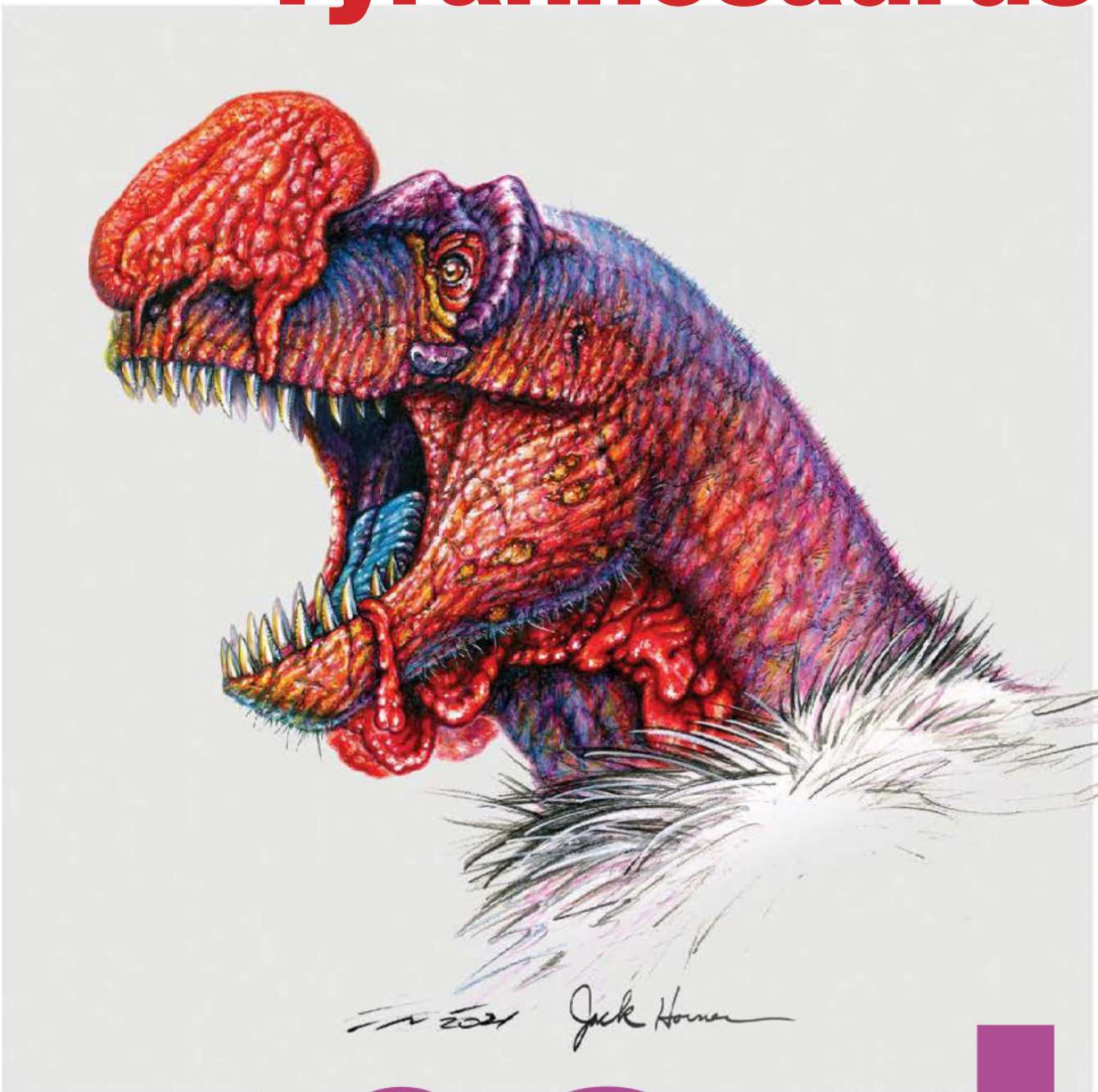
Hear more about social technology on our podcast, *The Science Briefing*

PETRA STOCK is a science journalist at Cosmos. Her last story for the magazine, on Mars gaming, appeared last issue.

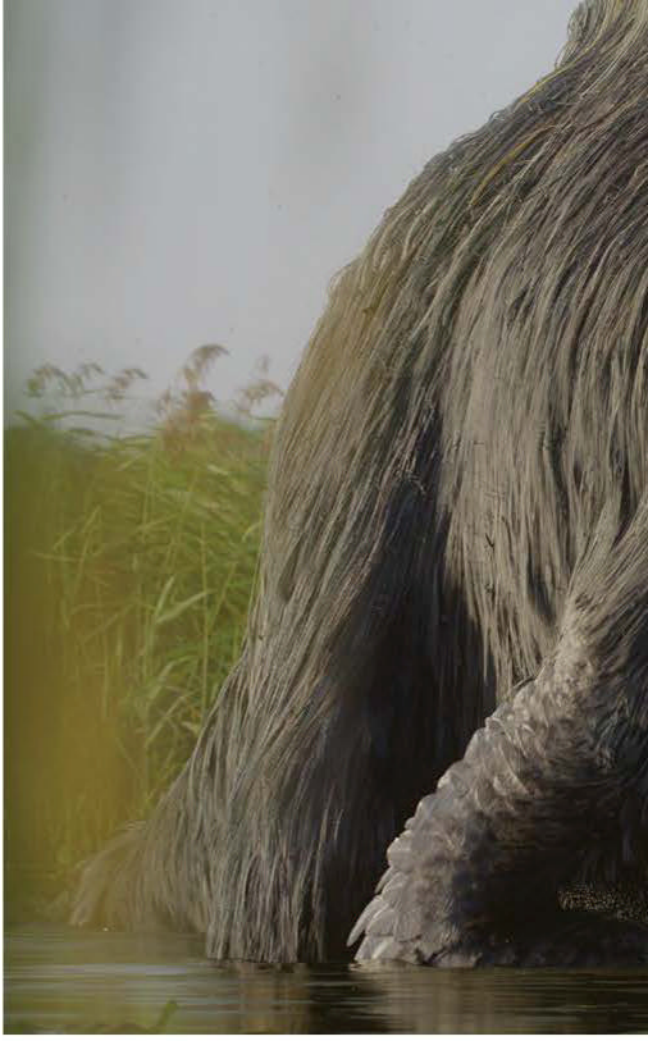
Aided by new discoveries and refined investigation methods, science is changing the way we see dinosaurs. A little colour doesn't hurt either, writes **Evrim Yazgin**.

UNIVERSAL PICTURES / GETTY IMAGES

Tyrannosaurus next



JACK HORNER, FABIO PASTORI



Close your eyes and imagine a dinosaur. I don't have any clairvoyant powers, but I've a pretty good idea of what most of you have conjured.

It's a *Tyrannosaurus rex* – right? It's the most famous dinosaur, and the easiest for most of us to picture. You're probably also seeing it as a big grey-brown monster akin to the 'rex' represented in Steven Spielberg's 1993 film *Jurassic Park*. Am I right?

There it is: seven tonnes of carnivore astride a grassy field against the backdrop of a lush, tropical forest under bright blue skies. There are likely herds of lumbering long-necked sauropods in the background of your mind's dino scene and a brown Triceratops or two as well. In fact, your imaginary *T. rex* is probably bounding after the horned Triceratops with an epic battle to the death ensuing as the picture plays out in your head.

This is the popular view of dinosaurs, informed by all sorts of media over the years. It's also, probably, mostly wrong.

Science is showing that much of what we've believed in the past about dinosaurs – from where they lived to what they looked like and how they behaved – isn't accurate. And, in fact, a lot of what is still put out for popular consumption lags far behind our scientific knowledge.

Top billing: dinos on screen

So let's start by playing fair: media representations of dinosaurs have come a long way.

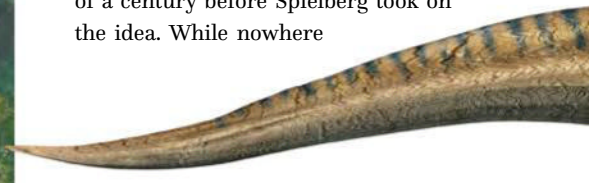
T. rex was discovered in 1902 in Hell Creek, Montana, US, by the American Museum of Natural History's famous fossil hunter Barnum Brown. Brown – aka 'Mr Bones' – is said to have been named after beyond-legend circus showman P.T. Barnum (1810–91).

Early reconstructions of the "lizard king" showed an erect, kangaroo-like animal. *T. rex*'s first media appearance was the 1918 film *The Ghost of Slumber Mountain*. Famed for its pioneering special effects work by Willis O'Brien, whose SFX later graced *The Lost World*, in 1925, Slumber Mountain featured a stop-motion *T. rex* vs Triceratops matchup three-quarters of a century before Spielberg took on the idea. While nowhere near as "realistic" as Spielberg's rex, there's something terrifyingly other-worldly about the 1918 version.

The inaccurate upright *T. rex* lived on in popular media well into the 1970s and '80s, despite scientific research having shown for decades a much more anatomically correct orientation of the bone joints.

While better in this respect, *Jurassic Park*'s "Roberta" (the official name of the film's main villain) still

Each generation of science and art brings new ways of visualising the palaeo past. The recent series *Prehistoric Planet* uses forefront technology to create species such as *Deinocheirus*, right, a towering omnivore that's taller than T. rex. The tyrant lizards – tyrannosaurids – have been a source of fascination since the field of palaeontology began. US paleoartist Charles R Knight's 1897 "Laelaps", below, made the species named *Dryptosaurus* widely known. In 1993 *Jurassic Park* cemented *T. rex*'s iconic status (previous pages, left). More recent dinosaur research suggests they were brightly decorated, incorporating colourful stripes (opposite bottom) feathers and even fleshy growths – as rex is imagined (previous pages, right) by renowned US palaeontologist Jack Horner.



CHARLES R KNIGHT / WIKIMEDIA COMMONS

lacks for scientific accuracy. It's too big; its skull is the wrong shape. And its behaviour, colouration and lack of feathers are all contentious issues.

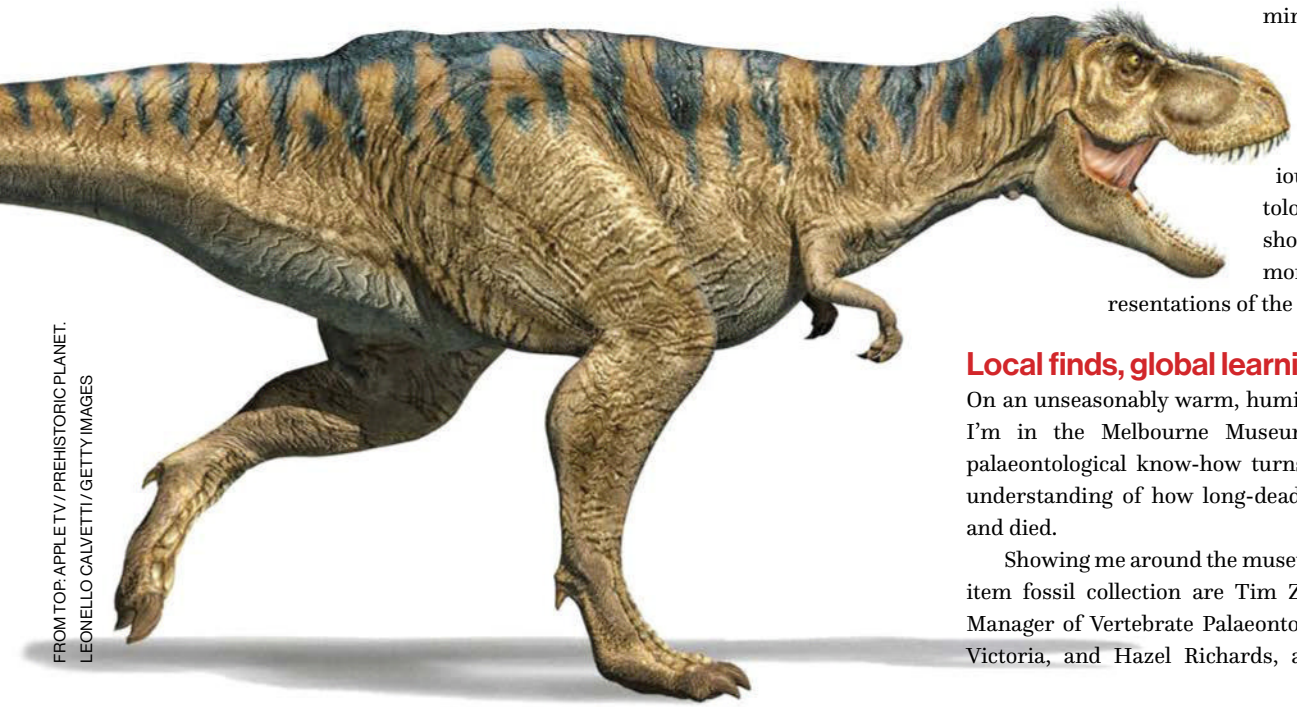
Dino-lovers of my generation grew up with the BBC's 1999 series *Walking With Dinosaurs*. I was four years old when I watched the documentary series, and it changed my life. It was a work of art and a scientific marvel and it sparked the imaginations of an entire cohort of nerdy kids. For the first time, dinosaurs were brought to life according to relatively up-to-date information.

But nearly a quarter of a century on, even this has become outdated. Does it matter? Well, yes.

The media's representation of dinosaurs has a huge impact into how they are perceived by the rest of us. Depicting scientifically accurate (or, as scientifically accurate as possible) dinosaurs can dispel myths and paint a much more interesting picture of these extinct creatures.

Last year the BBC released a new dinosaur documentary series, *Prehistoric Planet*. Narrated by Sir David Attenborough, the series picks up where *Walking With Dinosaurs* left off: it provides a visually stunning, scientifically backed view of dinosaurs to a new generation. The first episode begins with a *T. rex* mother and her feathered hatchlings – swimming of all things!

"There's no reason T. rex couldn't have been feathered and pink and danced and sang. Everybody just laughs at that. But it's just as accurate."



FROM TOP: APPLE TV / PREHISTORIC PLANET. LEONELLO CALVETTI / GETTY IMAGES

It's this kind of imaginative thinking about dinosaur behaviour that palaeontologists believe should be more commonplace in our representations of the extinct animals.

Local finds, global learning

On an unseasonably warm, humid September day, I'm in the Melbourne Museum to learn how palaeontological know-how turns a fossil into an understanding of how long-dead organisms lived and died.

Showing me around the museum's five-million-item fossil collection are Tim Ziegler, Collection Manager of Vertebrate Palaeontology at Museums Victoria, and Hazel Richards, a leading curator

behind the museum's latest prize possession – the near-complete fossil skeleton of the Triceratops affectionately dubbed 'Horridus'.

A seven-metre-long *Triceratops horridus*, Horridus lived about 67 million years ago – near the end of the era of the dinosaurs. The animal's one-tonne fossilised remains were found in 2014 in Montana and later brought to Melbourne; they represent the most complete real dinosaur fossil in any Australasian museum. In addition to the 266 bones that make up the main display (including the 261 kilogram skull), which opened in March 2022, curators sought to give a picture of the animal's habitat. Using a game engine, the team produced scenes from a forest clearing, an undergrowth, and a riverbank to illustrate the triceratops' environment. The scenes include turtles, crocodiles, other dinosaurs, and even early mammals.

Entering the museum's protective cool, dry and dark fossil store, Ziegler points to a fossil "assemblage" discovered in Victoria, which includes the fossil remains of many different species within the same rock. He emphasises that such complexes give us a picture of a local ecosystem.

One of the preserved animals is the "southern hunter" *Australovenator*. The largest theropod

dinosaur in Australia known from decent remains, *Australovenator* would have grown to around 5–6m in length. Ziegler hands me a 3D-printed copy of the ancient carnivore's claw: my very own *Jurassic Park* moment.

"While some dinosaurs are known from beautifully complete skeletons, most individual species are represented only by a few fragmentary fossils"

Ziegler and Richards explain that, more and more, palaeontology relies on the global fossil record.

"Our understanding of the appearance and behaviour of dinosaurs is shaped by the growing fossil collections in museums worldwide," Richards says. "While some dinosaurs are known from beautifully complete skeletons – like [Horridus] – most individual species are represented only by a few fragmentary fossils. But, because species that are

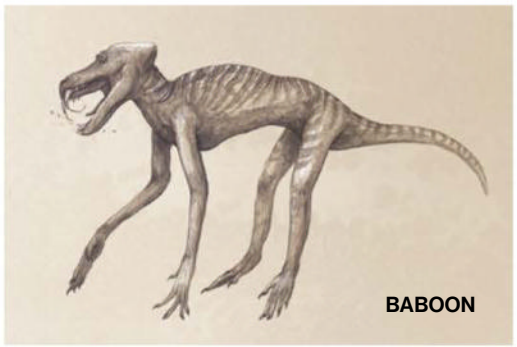
BARE BONES

Just how much information can you derive from a skeleton, anyway? Recent science has stretched into new fields exploring dermatology, anatomy, dentistry and spectography to try to form a clearer picture of what covered and decorated animals from the deep past. Palaeoartist C. M. Kosemen believes that many illustrations and popular depictions suffer from the "shrink wrap" effect: applying muscle but no fat or soft tissue, then laying the skin over the top.

"I was first prompted to draw this series when I saw x-rays of a crocodile," Kosemen told the *Daily Mail*.

"Even this dinosaur relative had far more fat, muscles and soft tissues on its body than most of our dinosaur depictions; which were as skinny as medieval paintings of plague victims."

Other common errors include the over accentuation of teeth and underestimation of soft tissue, for example an elephant's ears.



TOP: REUBEN COZENS/WIKIMEDIA COMMONS. LEFT: C. M. KOSEMEN X2

Pyroraptor (left and opposite top), a small, bird-like predatory dinosaur that hunted in the Late Cretaceous, certainly had feathers, but with scant information available, Paleorex has updated dull to a peacock palette. Horner's take (below) on the usually grey duck-billed *Maiasaura* is all about unknowns: colour and soft tissue.

closely related to one usually share many skeletal features, palaeontologists can generalise across related dinosaurs to infer the missing anatomy – at least until more fossils are found to fill in those gaps."

Palaeontology, like any science, benefits from technology advances. Ziegler points out that new, non-invasive techniques such as micro-CT scanning and even chemical preparations are less likely to damage the fossils than traditional methods. These methods necessarily integrate palaeontology with other science disciplines such as physics and chemistry.

One example I'm shown is an exquisitely well-preserved fossilised fish skull. The delicate bone looks like it could have belonged to an animal that died a few years ago: even its jaw hinges are preserved. But this fish lived more than 300 million years in the past.

"By looking at how living animals behave and use their skeletons, sometimes even tiny pieces of anatomy can tell us a great deal about how extinct animals like dinosaurs probably lived," Richards says.

In a smaller room housing fossil holotypes – the original specimens upon which a new species is described – we pause at the Victorian dinosaur *Leaellynasaura*. Ziegler explains that the 40 centimetre-tall herbivore, discovered in the late 1980s, changed the way that dinosaurs were perceived. It lived over 100 million years ago, when Victoria lay south of the polar circle. It was small, agile, and hardy – a far cry from the lumbering, monstrous dinosaurs that filled popular representations of old.

"The biggest transformation in our modern understanding of dinosaurs was arguably a series of discoveries in the 1960s–1970s that came to be known as the 'dinosaur renaissance'," says Richards. "These drastically changed how scientists thought about dinosaurs – from being slow, dopey creatures to dynamic, warm-blooded animals with complex social lives. Discovery and recognition of further important fossils led to our understanding that members of the theropod dinosaur group [the group that includes *T. rex*] evolved into modern birds."

But biases still hamper our ability to imagine what these magnificent beasts were like. How can scientists help overcome these enduring misconceptions? Richards notes the important role that even scientifically inaccurate representations can have.

"I think all palaeontologists agree that *Jurassic Park* is responsible for really bringing dinosaurs into the

FROM TOP: PALEOREX, JACK HORNER, FABIO PASTORI

public consciousness," she says. "It certainly sparked renewed interest in studying dinosaurs, and most palaeos today will speak of it fondly as an influence on their studies and their career.

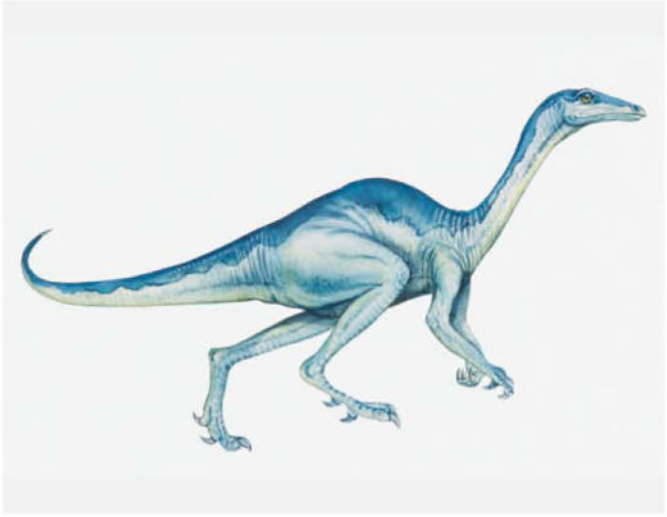
"Even 30 years and many sequels later, if the average person thinks of a *T. rex* you can bet it's the *Jurassic Park* rex they are imagining."

But what about documentaries? Richards says it's all about historical context.

"Any time you attempt to depict science on screen, you are taking a snapshot of the understanding at that specific point in time – but science is a process and as we discover new things, our knowledge grows and changes," she says.

"Palaeontology is no different. So, it's inevitable that in the decades since *Walking With Dinosaurs* in 1999 we will have discovered new fossils and advanced our thinking on how dinosaurs looked and behaved. *Walking With Dinosaurs* and even *Jurassic Park* both used the most up to date information available to them to present believable dinosaurs, and I think the care they took means these depictions still hold up really well today."

The pterosaur *Barbaridactylus* (above) and "wastebasket taxon" *Troodon* (below and opposite top) are examples of ancient animals known from scant physical evidence – one reason Horner (opposite below) urges creativity when re-creating dinosaurs.



Richards says *Prehistoric Planet* "established a new gold standard for dinos on screen. I wouldn't be surprised if little kids watching *Prehistoric Planet* thought the dinosaurs were real, the CGI and behaviours depicted were astoundingly realistic."

But some palaeontologists are worried that we're not going far enough in showing dinosaurs as real animals.

The fossil hunter's view

Jack Horner is arguably the world's best known palaeontologist (and, it's said, partly the inspiration behind *Jurassic Park*'s Dr Alan Grant, played by Sam Neill).

Horner has spent decades studying some of North America's most famous dinosaurs, like Triceratops and Tyrannosaurus.

Speaking via Zoom from his home in Montana, Horner is quiet yet authoritative – exactly as I remember him from the dozens of dino documentaries I watched in the 1990s and 2000s. The only difference is his hair has gotten wispier and whiter.

He believes that much of how we imagine dinosaurs – from how they look to how

FROM TOP: APPLE TV / PREHISTORIC PLANET; DORLING KINDERSLEY / GETTY IMAGES

they act – is still bound up with our own learnt biases.

"We have a lot of *T. rex* skeletons," Horner says. "We still argue about how they got their meat. I'm still a strong advocate of *T. rex* being an opportunist. The people that think that it's an apex predator – I think we have to think that this just based on opinion, their own biases, because there's no evidence for it.

"There are people that say there's a broken off [*T. rex*] tooth in an animal that survived afterwards. [Can they] show me exactly how the *T. Rex* had to bite this animal in order for a tooth to be lodged in the centrum of vertebrae and not alter the neural spine, which is the most fragile part of the thing? How do you actually break a tooth off inside of the hard part of the bone and not disturb the fragile part of the bone? It just doesn't make any sense – unless, of course, the animal was sitting or laying down on the ground already.

"Lots of scientists just want *T. rex* to be an apex predator and so they're going to do science the opposite way it's supposed to be done, they're going to look for evidence to support their theory."

"People have been making them grey and brown ... The preponderance of evidence suggests they would be vividly coloured because birds are dinosaurs"

Horner is particularly vexed by the how dinosaurs are painted... literally.

"Since the beginning of finding dinosaurs, people have been making them grey and brown. I say, since we don't know, a vividly coloured dinosaur is just as accurate as a brown one. The preponderance of evidence suggests that they would be vividly coloured because birds are dinosaurs and if they can be vividly coloured – especially the birds with crests on their heads or snouts; all of those bony crests are colourful – then why not at least vividly colour the accoutrements on the heads of the dinosaurs like the horned dinosaurs and the duck-billed dinosaurs?"

It all goes to the case Horner makes to promote an image of dinosaurs that's much more interesting.

"Theropod dinosaurs should be feathered and I think they should be colourful. Birds are pretty, and we assume they evolved prettiness on their own because dinosaurs couldn't be pretty.

"We assume dinosaurs have to be mean and nasty and eat people. That's our general consensus of dinosaurs, but there's nothing to suggest that it's right.

"Birds couldn't have evolved all of these incredible features all on their own. They were already birds, you know, long before dinosaur extinction. There's nothing to suggest that birds didn't acquire these features from their ancestors."

FROM TOP: JACK HORNER, FABIO PASTORI; KELLY GORHAM / MSU

LABYRINTHODON, IGUANODON AND MEGALOSAURUS IN COMBAT.

"I am loving the increased emphasis on dinosaurs as animals – showing them not just mindless bloodthirsty monsters ... but doing normal everyday things that we know animals do."

All singing, all dancing

"Dinosaurs probably weren't as exciting as we'd like to make them," says Horner.

"They were just normal animals. People trying to sell something, whether it be a TV show or a movie, are going to over-sensationalise the behaviours of animals."

Hazel Richards agrees: "I am loving the increased emphasis in media like *Prehistoric Planet* on dinosaurs as animals – showing them not just as mindless bloodthirsty monsters snarling and killing one another, but doing normal everyday things that we know animals do, and did in the past, like grooming, communicating, migrating, nesting, feeding.

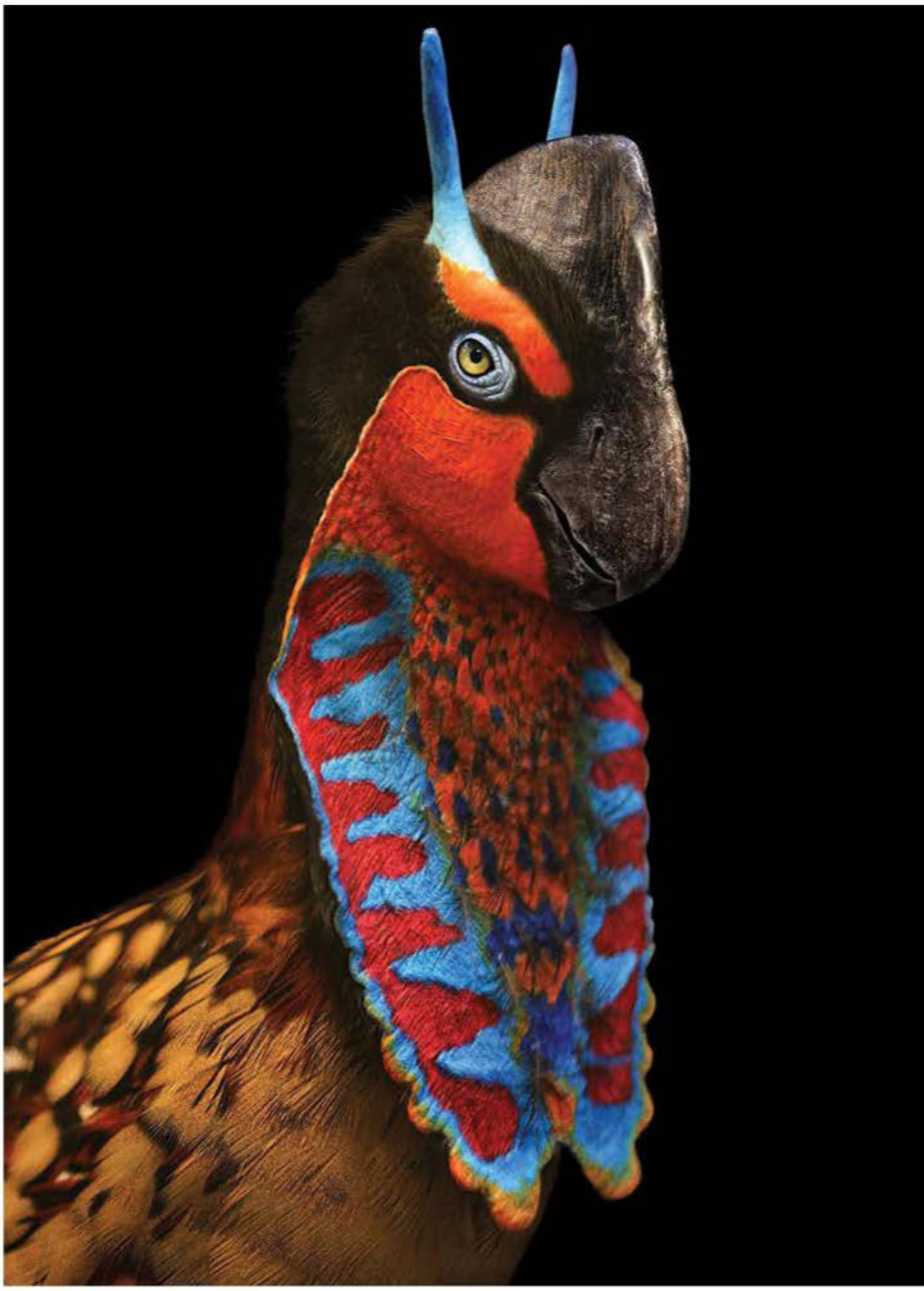
"Not necessarily 'thrilling' behaviours, but nuanced and believable and fascinating, nonetheless. I love the idea of kids growing up thinking of dinosaurs not as fictional beasts, but as real animals that walked the same Earth we do and were part of ecosystems as complex and interesting as those we see today."

Both Horner and Richards are adamant that we ought to get creative when it comes to depicting dinosaurs.

"I'm not that concerned with pedantic 'accuracy' of these newer depictions of dinosaurs," says Richards. "I find the speculative colours, soft tissues and behaviours shown in shows really interesting and engaging, and as long as they are presented as 'educated guesses' and not settled scientific consensus I think it is a great way to make people rethink their preconceptions about what past worlds were like."

"Scientifically accurate?" exclaims Horner. "We don't know they're accurate. I just don't like us staying with one thing that we don't know is right.

"Somebody recently made a model of Sue the *T. rex* as a big giant hippopotamus-looking thing, and



it's all grey. I don't understand that at all. I'd make it pink. Seriously. There's no reason *T. rex* couldn't have been feathered and pink and danced and sang. Everybody just laughs at that. But it's just as accurate as that big hippopotamus grey-coloured thing."

Not only should we consider updating how we see the dinosaurs we all know and love, says Richards, we should embrace the myriad animals that lived in prehistory.

Historic ideas of a snarling past (opposite top) have given way to familial bonds (above) in *Prehistoric Planet*. The oviraptor (below) gets a Paleorex makeover, (opposite) using existing avian embellishments.

"In the future I'd be super interested in seeing greater diversity of extinct critters on our screens," Richards says.

"Yeah, *T. rex* is cool, but we're discovering dozens of new dinosaurs every year, not to mention the vast array of other fascinating fossil species that would make for great viewing, like bizarre Cambrian invertebrates or early mammal-like reptiles."

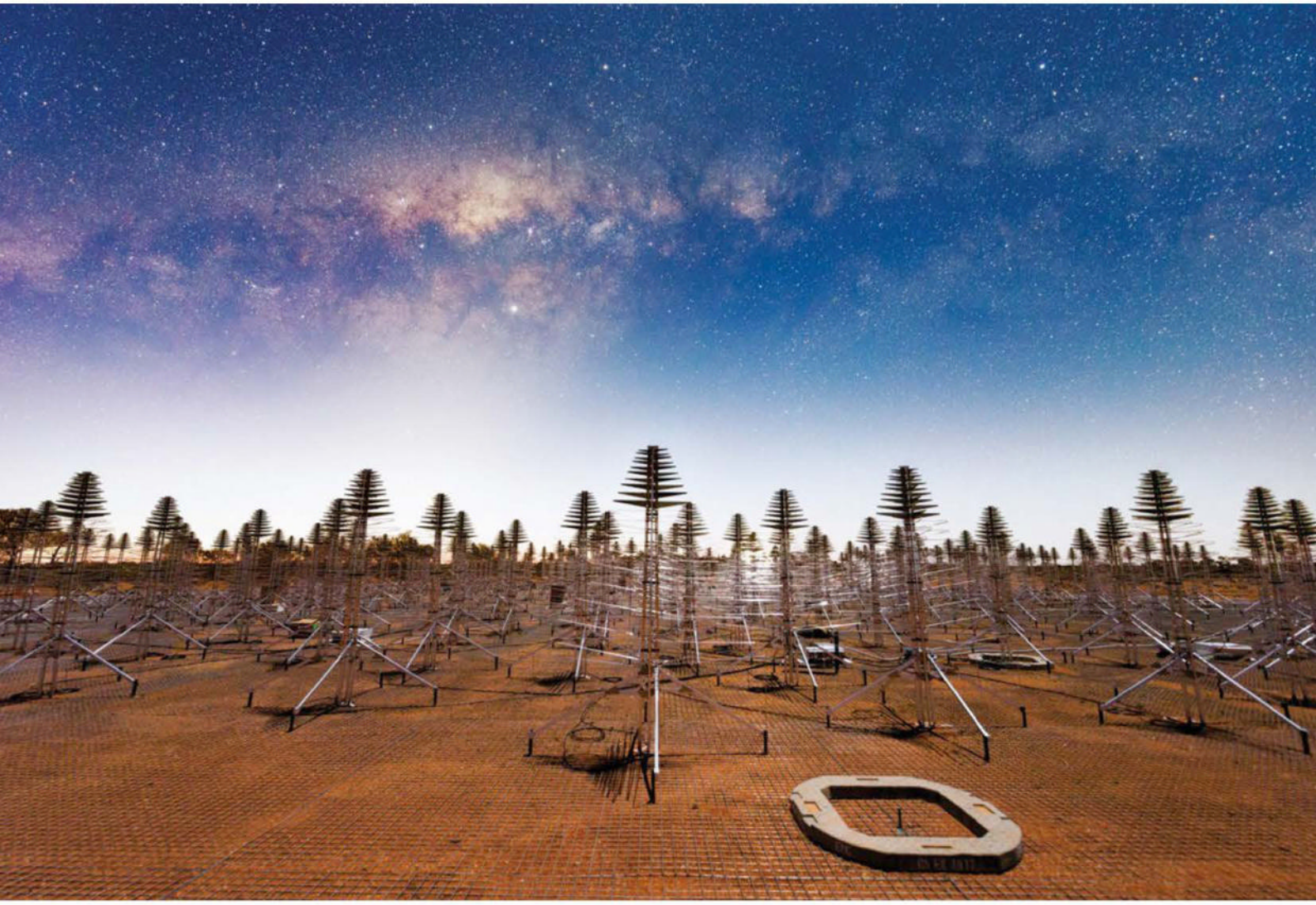
So: it could be your dinosaur imaginings from earlier need a bit of updating to keep up with scientific knowledge – and also for fun. Cast off those grey and brown overcoats and break out the bright party colours. More feathers. Louder voices.

Yes, dinosaurs were just animals doing normal animal things including eating, sleeping and general moseying about. But they may also have been more interesting in just about every way.

Now close your eyes and picture a dinosaur again. Maybe this time it's colourful, with ornamental feathers and a snood. Maybe it's dancing with its family. As palaeontological research continues to learn, let your imagination run wild.

EVRIM YAZGIN is a Cosmos journalist. His last story for the magazine – on AI and art – appeared in Issue 96.

LEFT, FROM TOP: BENOITB / GETTY IMAGES. PALEOREX. THIS PAGE, FROM TOP: APPLE TV / PREHISTORIC PLANET. DE AGOSTINI / GETTY IMAGES



GALAXY IN THE DESERT

When SKA-Low, the Australian component of the SKAO is complete, it promises a revolution in knowledge about our universe, and the possibility of other life within it. But, as **Jacinta Bowler** reports, another technological advance could scuttle SKA's discoveries, and the enemy is hiding in plain sight.

MICHAEL GOH, ICRAR-CURTIN

SKATELESCOPE.ORG

Currently in place (opposite) at the Inyarrimanha Ilgari Bundara, CSIRO Murchison Radio-astronomy Observatory in WA, the Aperture Array Verification System 2.0 is a demonstrator for SKA-Low. When SKA-Low is completed (artist's impression, above), antennas will be arrayed in 256-unit clusters called stations. The observatory's 512 stations will have more than 131,000 antennas.

Standing in the West Australian desert, at the site of what will one day be the SKA-Low, is uncomfortably hot, but beautiful. The only smells are outback breeze and sun-baked plastic marquee.

Red dirt littered with scraggly trees and tufts of grass goes on as far as the eye can see; the scrub has flowers I've never seen before. But this place is almost overwhelming in its remoteness – there's no WiFi, no phone signal – almost no way to contact the outside world.

But this lack of communication is by design.

The place was picked specifically for its inaccessibility. It's four hours' drive to the nearest town, Geraldton, and eight hours to make it back to Perth. The Shire of Murchison in which it sits has no recognised towns, a population of around 100 people and is approximately the size of the Netherlands.

By the end of the decade it will be home to a sprawling 65-kilometre long forest of metal trees. This eerie plantation will be quieter than most – its job will be to listen out for faint radio signals from the earliest parts of the universe, and record 'leaking' radio waves from nearby alien worlds.

To listen to the sounds of the universe, phone signal, planes, WiFi, even the reversing sensors on cars, will need to be silenced. If these antennas were ears, the radio signals blasting from our human made devices would be the piecing audio feedback squeal at a rock concert.

The area I'm standing on – Inyarrimanha Ilgari Bundara ("sharing sky and stars" in the local Wajarri Yamaji language), the CSIRO Murchison Radio-astronomy Observatory – has very minimal infrastructure. This makes the site radio quiet – an area where radio transmissions are restricted to ensure that the telescopes can do their job. The telescopes are bold projects, billions of dollars in the making. The most powerful of their kind on Earth, they will be able to peer further into the universe than any other telescope before. They could tell us more about black holes, gravitational waves and almost every part

of the universe – back to the earliest days after the Big Bang. They could even help us listen to aliens.

But far above is another technological wonder – megaconstellations of satellites, beaming down radio waves to provide internet to the world, including these radio-quiet areas. One or two satellites is manageable, but with businesses shooting thousands of satellites into space – around 1600 in 2021 alone – the sky is beginning to get noisy.

Connect with each other, or hear into the origins of the universe? Which is more important, and are both possible? Proponents of both are in an uneasy partnership to find a solution.

The SKA pipe dream

Conceived in 1991, the SKA project envisaged antennas spread over thousands of kilometres to 'simulate' a single device with the collecting area of a square kilometre. This engineering feat would have created undoubtedly the largest radio telescope of its kind on Earth.

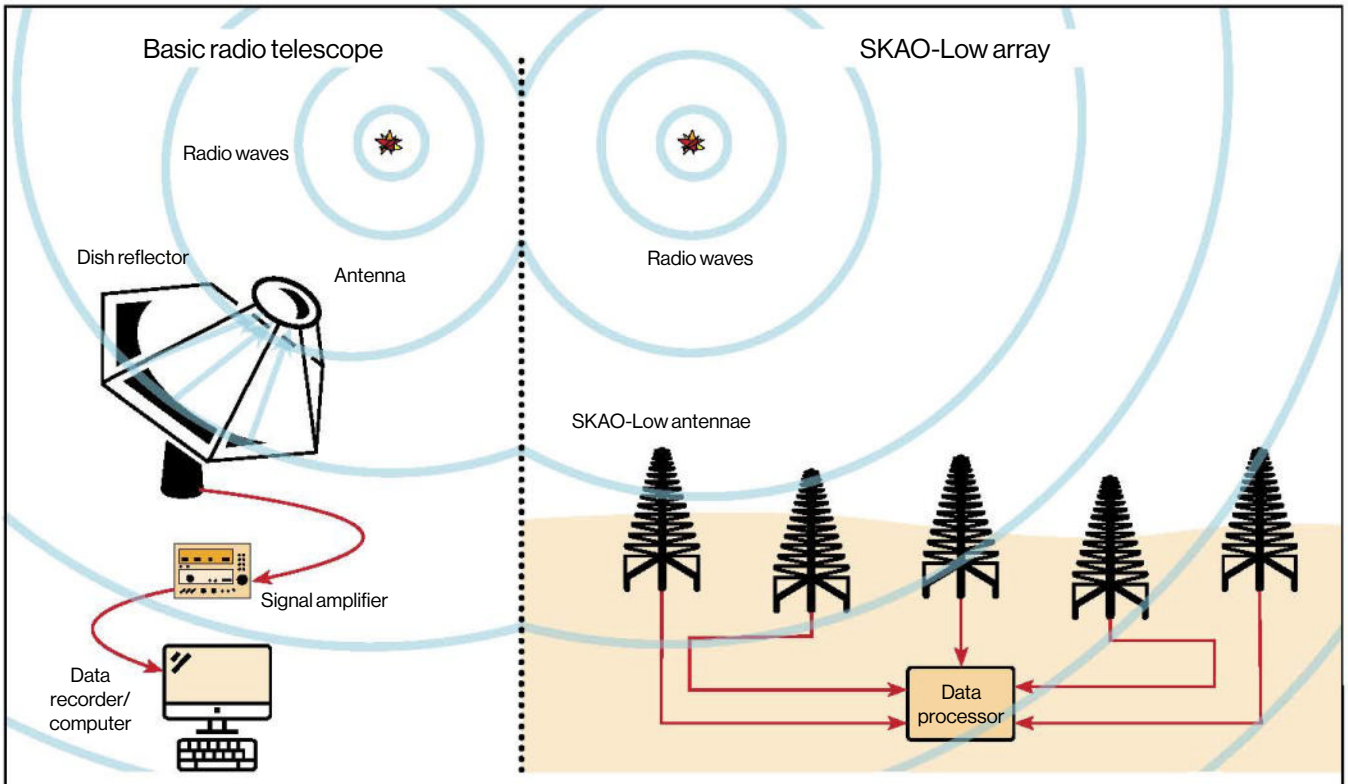
The final design, which has just begun construction in both South Africa and Australia, is two distinct giant telescopes – the SKA-Low in Murchison, and SKA-Mid, whose core station is inside the Meerkat National Park in South Africa. The whole thing is run by an intergovernmental organisation called the SKA Observatory (SKAO).

When the SKA-Low is complete, around 2030, 131,072 total antennas will form a 65km-wide spiral pattern, reminiscent of one of the galaxies it will be able to listen to. (The SKA-Mid looks a little more traditional, with 197 steerable dishes and 150km between the furthest two.)

Radio astronomy had humble beginnings. In 1939 amateur Grote Reber erected a 9m dish in his Illinois backyard and started surveying the sky.

Australia didn't get in the act until 1945 during World War II, when scientists from the CSIRO and the Air Force used a radar station to observe radio waves coming from the Sun that had been messing with radio equipment. This sort of experiment could be done today with a TV antenna – if there weren't louder TV signals getting in the way.

Sixteen years later, Australia got its first big radio astronomy telescope – the 64m diameter Parkes radio telescope, which received the live images of the Apollo 11 Moon landing in 1969.



In its simplest form (at left), a radio telescope has one or more antennas for picking up radio waves, a receiver and amplifier to boost the signal to a measureable level, and a device to keep a record of the signal. The SKA-Low (at right) is described by its parent organisation SKAO as a "mathematical" telescope that filters out what's not desirable in the observable sky. The SKA-Low array's 131,072 individual antennae are fixed, so astronomers will use data processing to "point" them – a technique known as "beamforming". The data volumes generated will be astonishing: multiple terabytes per second, which next-gen supercomputers will process at as-yet-unachieved speeds.

GREG BARTON X2

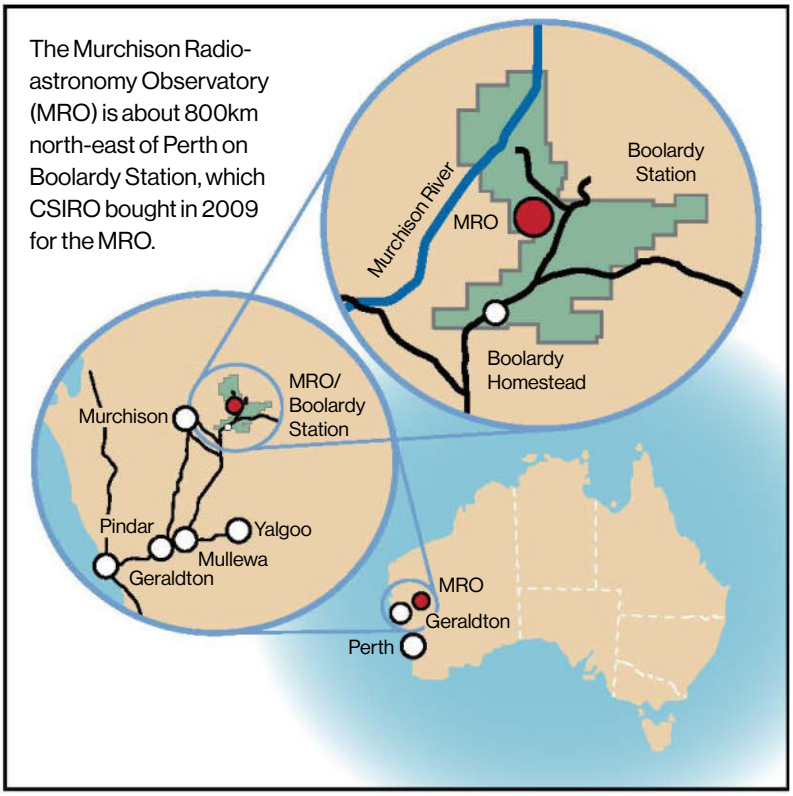
Despite our slow start, radio telescopes are particularly well placed in the Southern Hemisphere. There are fewer people, and therefore less interference from human radio signals. But the Southern Hemisphere is also looking at a whole different patch of sky to scientists' northern colleagues.

If the Parkes telescope is movie famous because of the Australian classic *The Dish*, the movie *Contact* ensured the larger Arecibo Telescope's fame. Arecibo was a 305m diameter radio telescope built into a natural sinkhole in Puerto Rico and was well known for programs to search for extraterrestrial intelligence. In 1974 the telescope was used to transmit a simple pixel picture message for aliens to nearby globular cluster Messier 13.

Compared to Arecibo and Parkes, the SKA telescopes are, technically, ginormous. SKA-Low's array forms a virtual radio telescope 65km in diameter, with a collecting area of more than 400,000 sq.m. The SKA-Mid acts like a 150km diameter telescope.

Understanding the marvel of SKA-Low starts at the high-tech metal Christmas trees. At 2m tall, they have solid metal 'branches' near the top, which become larger wire branches below. These lower branches look just like wire coat hangers, but upside down, becoming larger as the tree gets closer to the ground.

Each tree works in a similar way to the antenna on your car, picking up radio waves. Except while your car radio might be trying to pick up the 'loud' FM signal band of 87.5–108 megahertz (MHz), the antenna is trying to pick up any faint signal from a wider range: between 50MHz and 350MHz. This includes everything from television and radio broadcasts, to police scanners, CT scans and cordless phones. More importantly for the telescope, ancient hydrogen, galaxies and other space objects can also be mapped.



The SKA telescopes are ginormous. SKA-Low's array forms a virtual radio telescope 65km in diameter, with a collecting area of more than 400,000 sq.m.

The antennas will be in groups of 256, each one called a station (although they look a bit like little forests). There are 512 stations – 131,072 total antennas. Some of these stations will cluster in the centre, while the rest arc out in three spiral arms. About 65km will separate the ends of the longest spiral arms – a 40-minute journey at highway speeds.

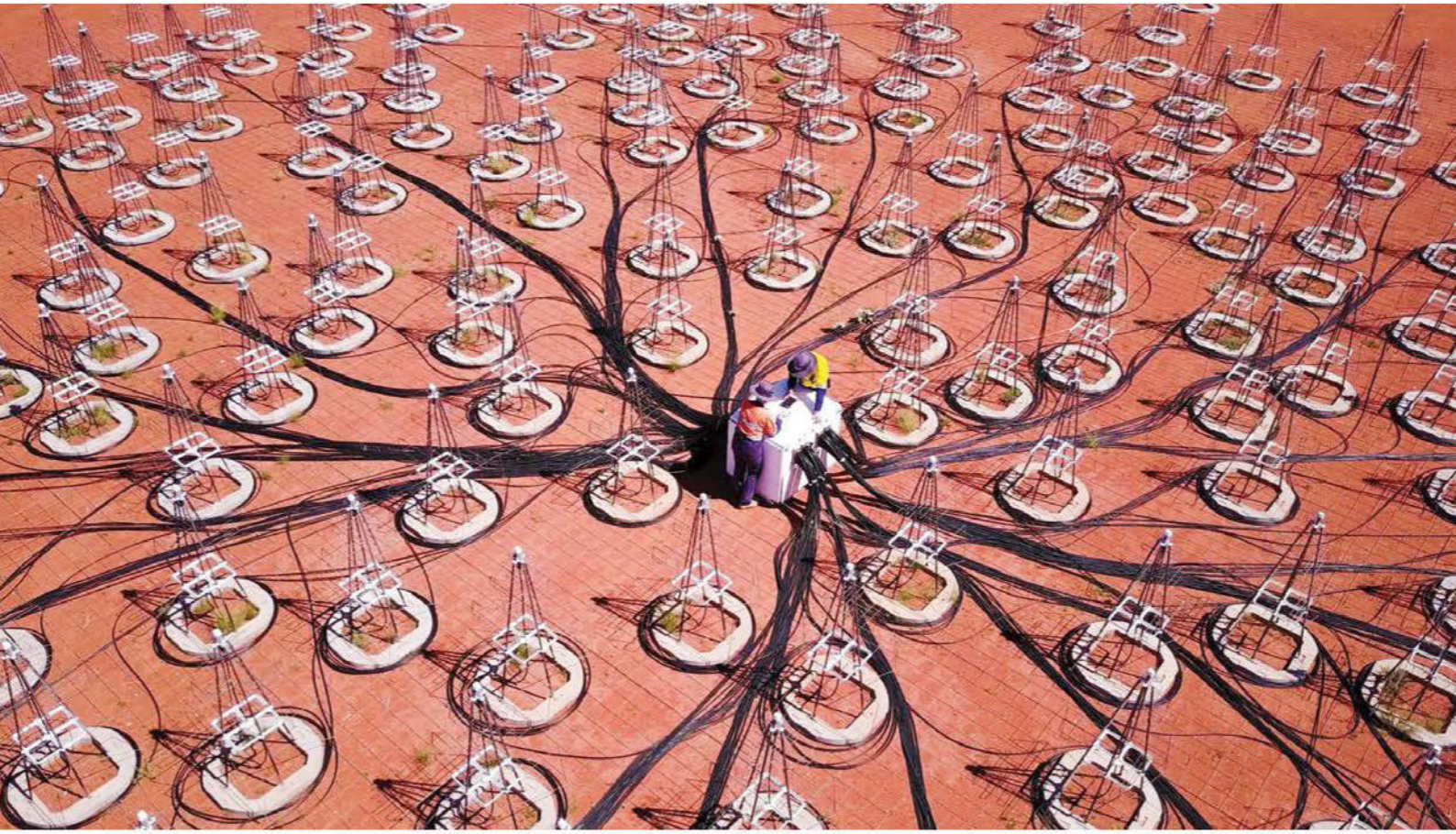
From the air, it will look a little like a glinting metal galaxy – perhaps like a Hubble or Webb image, with red shimmering in the background.

Just one Christmas-tree antenna isn't much better than your TV antenna – it picks up whatever it hears, with no ability to distinguish where it's coming from. Instead, you need antennas spread widely to create a larger bucket to catch those faint radio waves.

A traditional radio telescope is made up of one big three-dimensional dish. This dish receives the radio waves then redirects them towards a receiver in the middle of the telescope, which is a point above and in the centre of the dish usually elevated by pieces of metal. These dishes can also be manoeuvred to face a desired direction for radio signals.

But SKA's antennae are fixed. Instead, they are digitally pointed – a technique called "beamforming". With thousands of antennas spread over 65km, radio signals from the same source will hit the antennae at different times. Imagine a sphere of radio waves colliding with the sphere of our Earth. A 'point' of the sphere is going to be first to touch us. In this example let's assume that it's at the centre of the SKA-Low formation. First, the central antennas pick up the radio waves. Then, as more of the sphere interacts, it looks like a ripple effect, spreading outwards towards the edges.

To make sense of this, the technology behind the telescope – the central signal processor – uses aperture synthesis to match up the radio waves. (Aperture synthesis was first formulated by Australian radio astronomers Ruby Payne-Scott and Joseph Pawsey



in 1946.) This creates a 3D telescope, but the third dimension isn't depth – it's time.

And SKA has the potential to find aliens.

Human communications, broadcasts and later televisions and mobile phones have been gushing radio waves since we started radioing to ships a century ago. Some of these regular radio waves are blocked by the ionosphere, but some – especially TV broadcasting and those from satellites – can leak outside of our planet: Earth's technosignature.

If another alien civilisation in our cosmic neighbourhood was doing the same, the SKA is the first telescope that could potentially pick up other technosignatures. When complete, each SKA is so sensitive it could detect a signal from a mobile phone on Mars – 225 million kilometres away.

"It doesn't necessarily need to be beamed towards us or deliberate," says Professor Cathryn Trott, SKA-Low's Chief Operations Scientist.

But while some might be fascinated by the alien component, Trott is more excited by SKA's other important strand of research: identifying ancient hydrogen that spewed into our universe shortly after the Big Bang. This hydrogen could allow researchers to map what the universe looked like at its "epoch of reionisation" over 13 billion years ago. This could help scientists understand when the first galaxies formed, and what else was happening in these first years of the universe.

The SKAO didn't emerge fully formed in the recent past. The astronomy community's desires and ideas that led to it first coalesced in the late 1980s. A shortlist of potential technologies was known in 2005. The SKA Organisation was created in 2011; the dual site selection of Australia and South Africa was settled in 2012. In 2018, the first prototype (opposite top) SKA-Low station – Aperture Array Verification System, AAVS1 – was completed. AAVS1.5 (above) swiftly followed, in 2019.

This cosmic number of antennas, plus the interferometry and beamforming to make it work, requires thousands of processing modules worth of computing power from the central signal processor. But this pales in comparison to the mind-blowing amount of data that comes out of it.

Whenever they are running, both SKA telescopes will produce up to five terabytes per second of measurement data each: equivalent to downloading 200 HD movies every second.

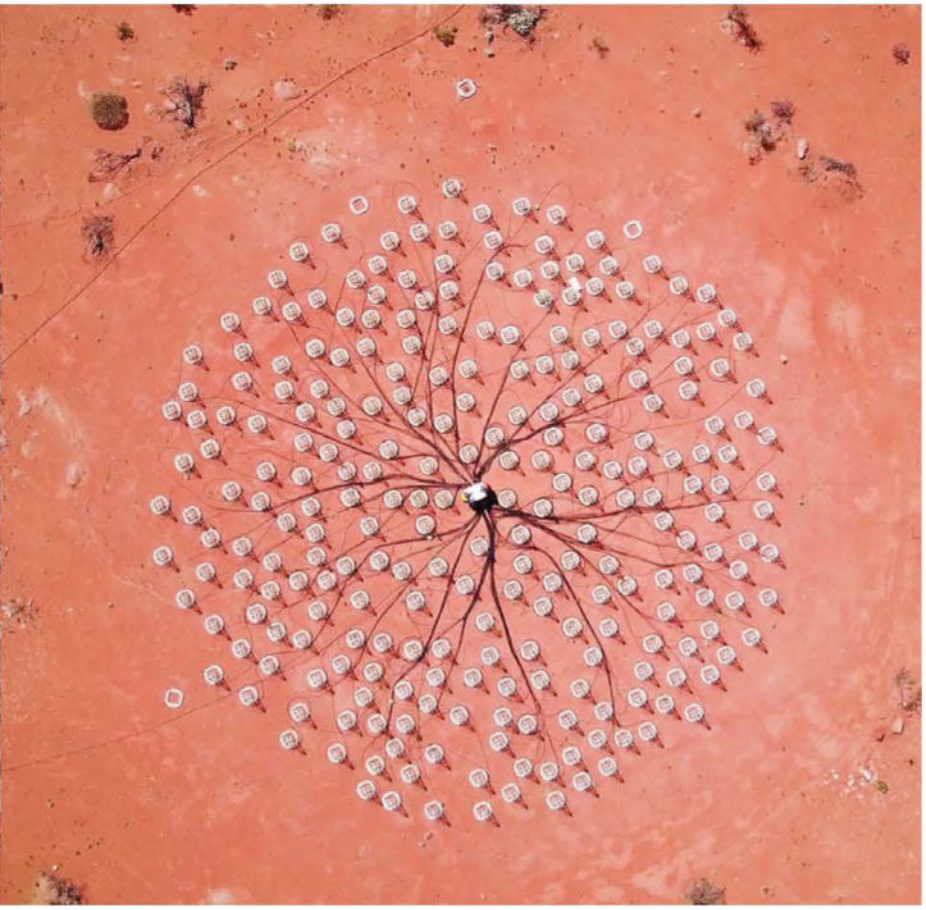
This data travels through optical wires to the Pawsey Supercomputing Centre in Perth, almost 800km south-west, where the vast amount of material is analysed at a processing speed of around 135 petaflops – that's almost 100,000 times faster than a top-of-the-line smartphone.

Once the supercomputer is fully operational, it'll be 25% faster than the current fastest supercomputer in the world.

While the SKA telescopes are still in their early stages, the excitement is palpable. There's so much out in the universe yet to be uncovered.

But the long-planned, multi-billion-dollar project only works if the telescopes aren't just overhearing our planetary chatter.

SKATELESCOPE.ORG X2



Shuttle was being reused back in the 1980s), the company has recently succeeded in creating partially reusable launch systems, pushing down the costs of rocket launches.

Smaller, cheaper components have also allowed more institutions and companies to launch satellites for a fraction of the previous cost.

This, along with the drive to give rural and remote areas internet access, has led to 'mega-constellations' of satellites. Starlink has launched more than 3000 of a planned 12,000 strong satellite fleet. Amazon has 3,000 satellites planned and OneWeb is deploying another 600.

The more satellites there are, the more of the planet gets access to regular and reliable internet. The more companies, the more competition – potentially pushing down the price.

But for astronomers, according to Dr Phil Diamond, the SKAO Director General, "they're a pain in the arse".

Federico Di Vruno has broad shoulders, a bald head and eyes that crinkle up when he smiles. Originally from Argentina but now living in the UK, he spent our Zoom call sipping on maté – out of a silver curly straw.

He lives on the other side of the world to both SKA-Low and -Mid, and yet he's a key to the multi-billion-dollar projects being a success.

Satellites far above

Almost a lifetime ago, the first artificial satellite was catapulted to the skies. The Soviet Union's Sputnik 1 was launched from Kazakhstan in October 1957 and for 21 days it transmitted a single repetitive beep tone that could be heard by any curious amateur radio operators.

Since then, we've been slowly adding satellites to our low earth orbit, launching around 100–200 objects into space every year.

Having eyes far above the Earth's surface is critical for science. There's the International Space Station, along with weather, fire and greenhouse-gas-monitoring satellites. Satellite phones and internet have long been a mainstay of rural life.

When the Hubble Space Telescope launched into low Earth orbit in 1990, there were about 400 active satellites buzzing around.

By 2000 there were 700. Ten years later that number had just scratched 1,000. But in the mid-2010s launch numbers began to skyrocket. By the time you read this, there will be over 10,000 satellites in Earth's orbit, around half of them active.

This explosion of satellites has been spurred on by two technological advances. Although Elon Musk's SpaceX wasn't the first to design reusable spacecraft or launch components (NASA's Space

Because Starlink's job is to provide satellite internet access around the planet, even radio-quiet areas are at risk from stray internet radio beams.

The spectrum manager tells me that he used to be a satellite engineer; he's still an engineer at heart.

"It gives me a really interesting perspective, because I understand satellite people," he says.

"These constellation operators are engineers. Of course, they care a lot about astronomy, and they want to try to use space in a sustainable way."

In 2018, when SpaceX launched the first few Starlink satellites, astronomers knew that these satellite constellations could be problematic.

And because Starlink's job is to provide satellite internet access around the planet, even remote or radio-quiet areas like Inyarrimanha Ilgari Bundara and Meerkat National Park and their highly sensitive radio telescopes are also at increased risk from stray internet radio beams.

Generally, the frequencies of radio waves are carved out for different purposes, including broadcasting, radar, or mobile phones.

Even outside radio-quiet zones, radio astronomy has teeny slivers cut out of the allocations to allow for scanning the heavens. Today's radio astronomy needs access to the full spectrum of frequencies – galaxies have a different frequency to pulsars, which have a different frequency to ancient hydrogen. To do full sky surveys you need to listen across multiple wavelengths to get a proper picture.

This is why radio-quiet zones are so important.

"This unprecedented level of radio frequency interference control was a significant factor in Australia's successful bid to host SKA-Low," writes CSIRO radiocommunications engineer Carol Wilson. "It has already led to world-class astronomy results in frequency bands that cannot be used elsewhere in the world, particularly in 700–1000 MHz."

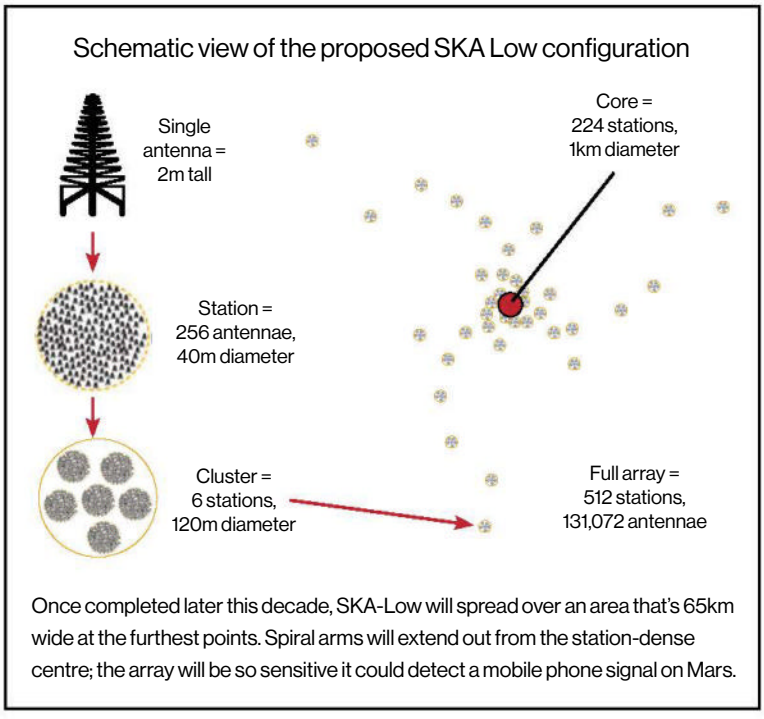
But zone regulations are only enforceable on the ground, not in the air or in space. Satellites can legally do whatever their owners like.

SKAO's analysis suggests that without mitigation, SKA-Mid is likely to lose data between 10.9 and 12.75 GHz – the radio wavelength that satellites use to contact the ground. But with hundreds of thousands of satellites constantly beaming down, the Band 5b receivers – which range from 8 to 15 GHz – could be completely lost.

SKA-Low – which is observing in a lower frequency range – will have fewer issues. However, CSIRO is still studying the impact of having the satellite internet user terminals near the site.

Di Vruno's job is to work with satellite companies to come to an agreement on how megaconstellations and radio telescopes can exist in harmony.

In November 2019 (above), a batch of 60 Starlink satellites are readied for deployment from the upper stage of a Falcon 9 launch vehicle.



Once completed later this decade, SKA-Low will spread over an area that's 65km wide at the furthest points. Spiral arms will extend out from the station-dense centre; the array will be so sensitive it could detect a mobile phone signal on Mars.

"Lower Earth orbit is big but not huge – and definitely not infinite," he says. "The numbers [of satellites] we are managing right now: they're large, but not so scary.

"But the plans out there to launch all these satellite constellations is quite scary because the numbers get up to 500,000 satellites." In true engineer understatement, he adds: "That's a lot."

This has led to virtual meetings and straight talking with the world's largest tech and space companies. It has taken him to the United Nations Committee on Peaceful Uses of Outer Space (COPUOS) to advocate on behalf of ground-based telescopes worldwide for access to 'dark and quiet' skies.

The February meeting of the COPUOS Scientific and Technical Subcommittee was the second time that dark and quiet sky protection was a distinct agenda item – Di Vruno and the team were ecstatic about the result.

"We have over 160 members now, and the four hubs are working in many different work packages like coordinating satellite observations, engaging with industry and others," he says.

"It's interesting to see how things have changed [since] we started having this conversation."

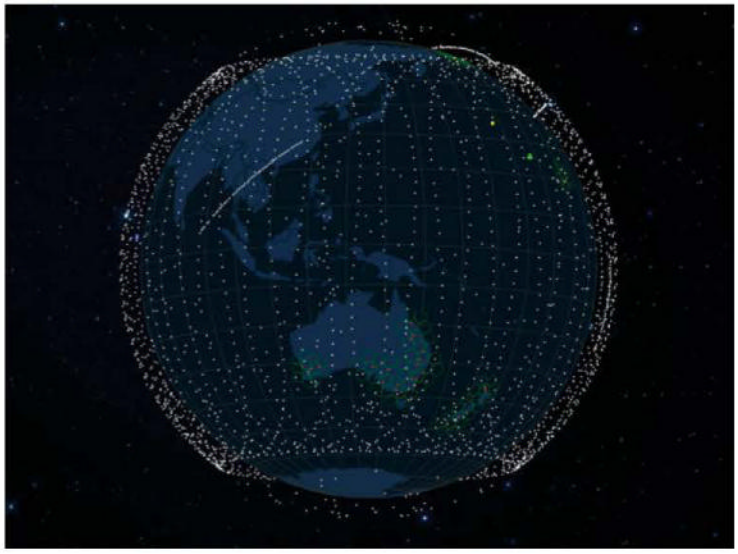
Sharing Sky and Stars

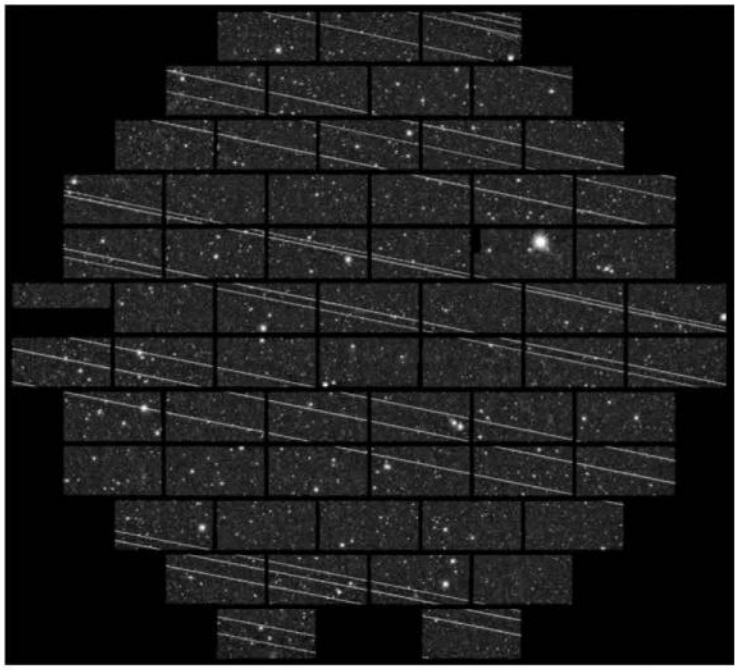
Astronomers themselves are beginning to come up with answers. The team behind an SKA 'precursor' called the Murchison Widefield Array (MWA) have found a way to cancel out radio interference.

"We're trying to do radio astronomy here on the MWA with satellites creating all sorts of interference," says Professor Elanor Huntington, a CSIRO executive director. "The people who were doing that

LEFT: GREG BARTON. ABOVE: YOUTUBE.COM/@SPACEX

SKAO's analysis suggests that without mitigation, SKA-Mid is likely to lose data between 10.9 and 12.75 GHz – the radio wavelength that satellites use to contact the ground.





had to figure out a bunch of signal processing, to essentially look past all of the noise that the satellites were making."

Using the MWA as a passive radar, "they have now also figured out how to flip that round, so that they can make a company that is ... specially designed to look for those satellites for the space industry."

Coordinating where satellites are allows researchers to schedule observations around them – but more satellites means more cuts into observing time.

Industry is also engaged. Despite a difficult start – Elon Musk allegedly told astronomers that if they were clever, they would just put their telescopes into space – Starlink has been working to try and solve both the brightness and radio problems.

"Starlink is actively avoiding some radio observatories in the world," says Di Vruno. "That's something that is being implemented now."

Murchison's radio-quiet zone is a 260km-radius circle, and when Starlink launched in Australia, they left a 70km-radius hole over the most crucial inner area closest to the telescope.

Like many truces, this one is on uneasy territory. Recently, after assessing that the telescopes in the area use different frequency bands to the ones the satellites are using, that hole on the Starlink map quietly closed. And Starlink isn't just one satellite comms enterprise in the market. Di Vruno's bridge-building work is far from over. He's upbeat about his mission, although you can tell that there's tension there too.

"It is a challenge for sure. But I don't think that this is the end of radio astronomy at all."

This much is certain: The SKA telescopes are going ahead, satellite constellations or not, and its proponents and creators are consumed with the possibilities it brings to astronomical discovery.

"I was in CSIRO when the first science data started coming out of [SKA predecessor] ASKAP. Going to the meetings and morning teas with the astronomers as they started bringing the first images... that's amazing," says SKA-Low director Pearce.

"I must admit to having watched the press conference for the first James Webb Space Telescope images and thinking how exciting it's going to be when we can do the same."

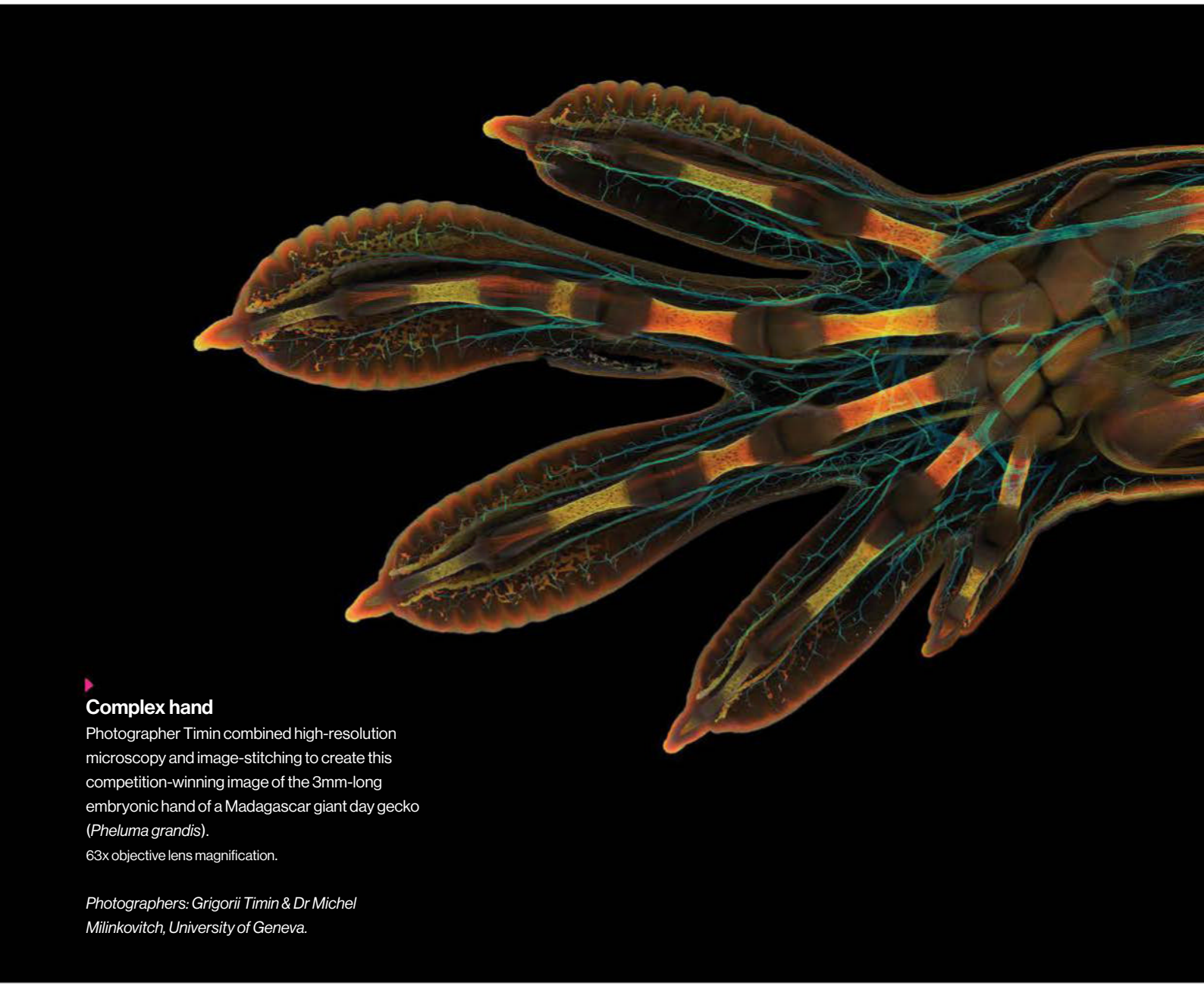
A live snapshot (top) of Starlink satellites over Australia on 22 February 2023 shows their proliferation. In 2019 (above), optical astronomers at the Cerro Tololo observatory, in northern Chile, surmised that streaks on their images were due to a batch of satellites launched the week before.

FROM TOP: SATELLITEMAP.SPACE; CTIO/NOIRLAB/NSF/AURA/DECAM DELVE SURVEY

JACINTA BOWLER is a science journalist at Cosmos. Their last story for the magazine appeared in issue 96, and a previous story, on the hunt for dark matter, was included in *Best Australian Science Writing 2022*.

Small world wonders

Remarkable, colourful and confronting, the entries to Nikon's 2022 Small World Photomicrography competition were as dazzling as ever.



Complex hand
Photographer Timin combined high-resolution microscopy and image-stitching to create this competition-winning image of the 3mm-long embryonic hand of a Madagascar giant day gecko (*Pheluma grandis*).
63x objective lens magnification.

Photographers: Grigorii Timin & Dr Michel Milinkovitch, University of Geneva.

Mother's milk

The 2nd place photo reveals breast tissue with contractile myoepithelial cells – natural tumour suppressors – wrapped around milk-producing alveoli. The photographer works in the WEHI's Department of Immunology.

40X objective lens magnification.

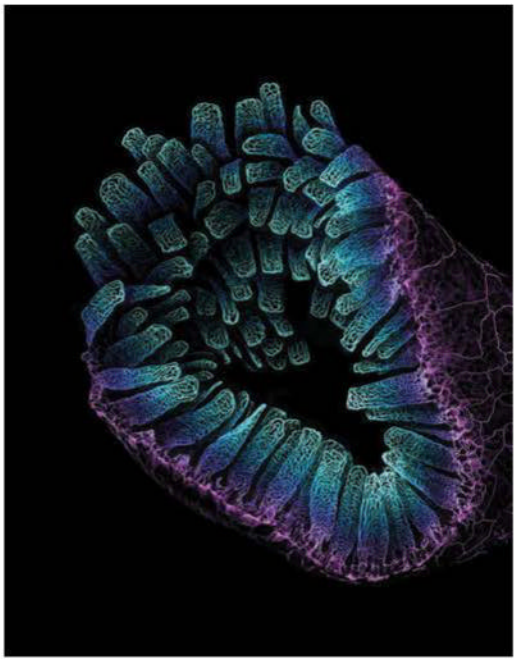
Photographer: Dr Caleb Dawson, Walter and Eliza Hall Institute, Melbourne.

Foodline focus

Blood vessel networks in the intestinal villi of an adult mouse glow green; villi help the animal's gut absorb nutrients. Third placegetter.

10X objective lens magnification.

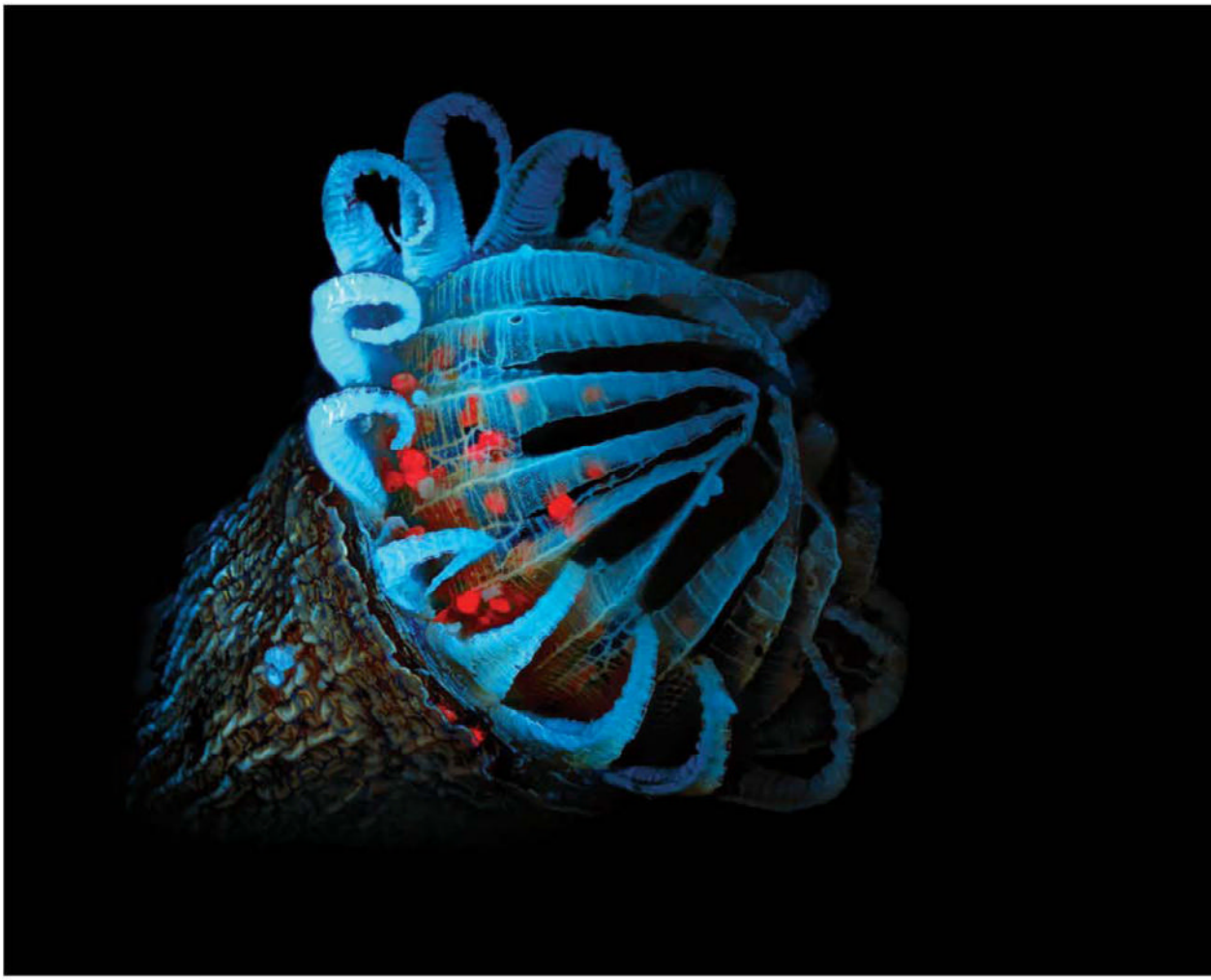
Photographers: Satu Paavonsalo & Dr Sinem Karaman, University of Helsinki.



Carbon escape

Molecular mayhem, the sixth place image shows unburned particles of carbon released when the hydrocarbon chain of candle wax breaks down.
2.5X objective lens magnification.

Photographer: Ole Bielfeldt, Cologne, Germany.



Mossy capsule

Looking more alien invader than natural vessel, a sporangium – moss spore capsule – is the receptacle in which moss spores are stored prior to release. The blue structures in this Image of Distinction are peristome teeth, which manage a gradual, rather than all-at-once, release of spores.

20X objective lens magnification.

Photographer: Michael Landgrebe , Berlin, Germany.

Forest devil

Camponotus – carpenter– ants are a genus of 1,000 or more species found in forests worldwide. They're generally large – workers of some species reach 13mm; queens 20mm – and rather fearsome looking, should you get as close as this Image of Distinction.

5X objective lens magnification.

Photographer: Dr Eugenijus Kavaliauskas, Lithuania.

Opening hour

Speckled with pollen, the stamen of a four o'clock flower (*Mirabilis jalapa*) unfurls in this Image of Distinction. *M. jalapa* was grown by the Aztecs for beauty and medicine; flowers open between late afternoon and dusk.

6X objective lens magnification.

Photographers: Gabriel Fernández & Fernández Jorge Alberto, Argentina.

Colourful fly-worm

This pastel-shade rendering of a midge larva was awarded Honourable Mention.

10X objective lens magnification.

Photographer: Karl Gaff, Ireland.

Nervous hues

The photographer used fluorescence to highlight nervous system components in this transgenic axolotl: Schwann cells (cyan) around the eyes and axons (magenta) in the interior. Awarded Image of Distinction.

1X objective lens magnification.

Photographer: Dr Marko Pende, MDI Biological Laboratory, Maine, US.

Protective roll

Marram, or European beachgrass (*Ammophila arenaria*) grows in beach dunes across Europe and North Africa. This leaf cross-section, an Image of Distinction, shows the plant's habit of rolling its leaves to conserve water.

20X objective lens magnification.

Photographer: Anatoly Mikhaltsov, Children's Biological and Ecological Center, Omsk, Russia.

Bamboo curve

Honourable Mention went to this cellular marvel: a young stem of *Fargesia* sp. bamboo. Unlike the fast-growing, aggressively spreading bamboo genera, *Fargesia* clump and are easy to maintain in ornamental gardens. Some Fargesias are important foods for giant pandas.

10X objective lens magnification.

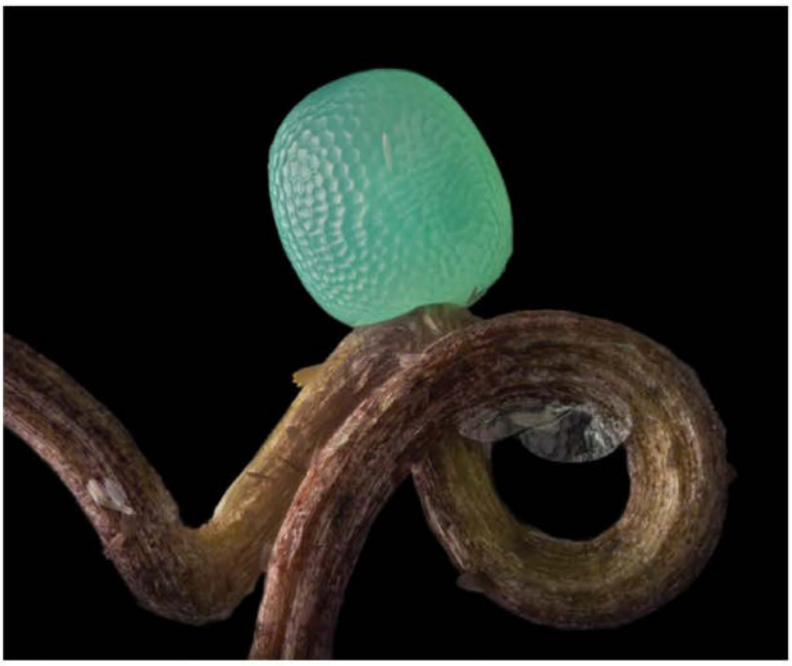
Photographer: Gerd Günther, Düsseldorf, Germany.

So flutter by

Seen in detail, the eggs of many butterfly species resemble bespoke lamp-glass: surely only an artist could render such beauty. In 2–3 days a caterpillar will emerge and commence the prosaic business of munching at plants. This egg and its supporting stem of equally beguiling form were awarded Honourable Mention.

10X objective lens magnification.

Photographer: Ye Fei Zhang, Jiangsu, China.



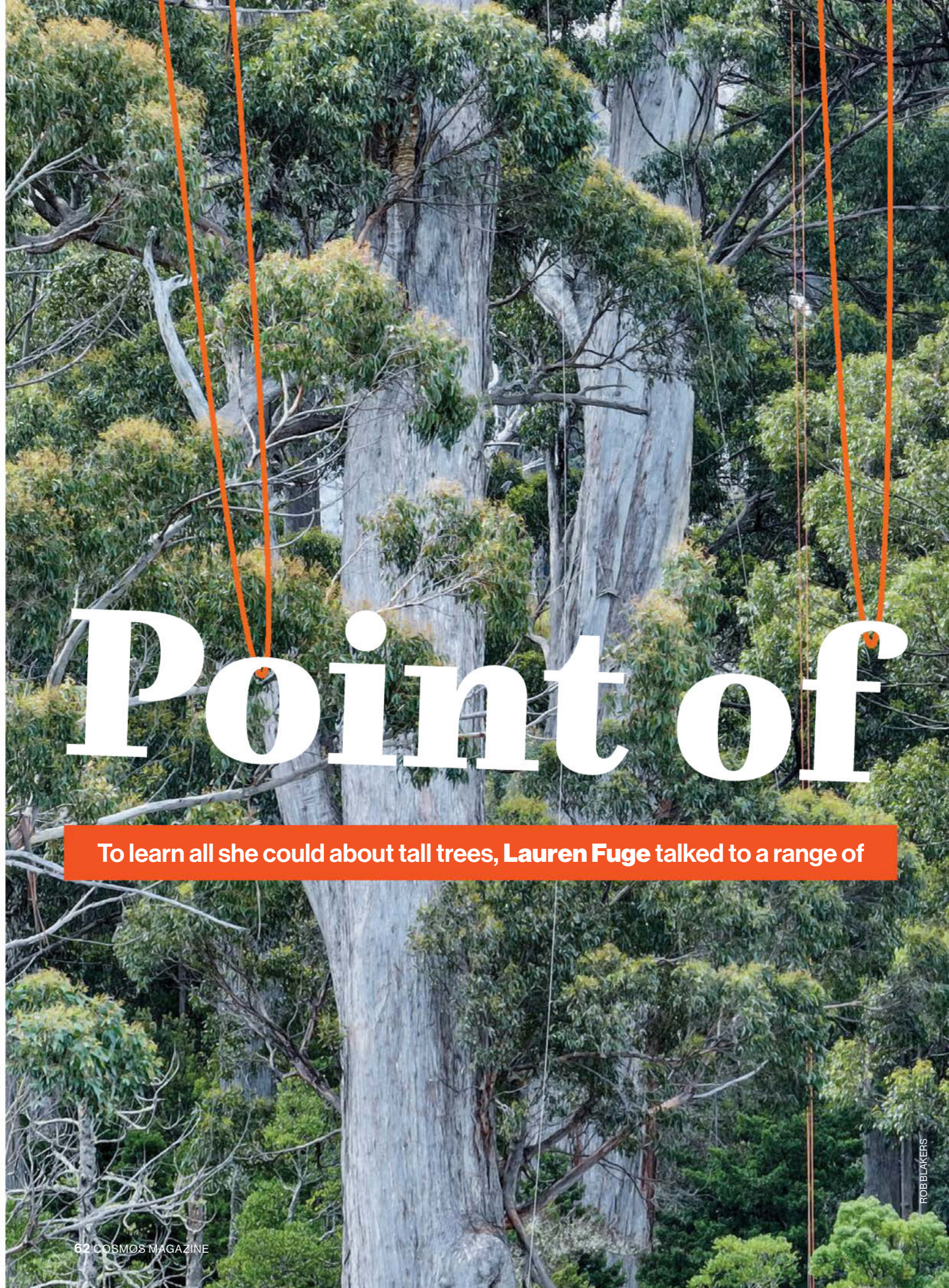
Sting in the tail

In this Image of Distinction, the lower abdomen and stinger of a small paper wasp, genus *Protopolybia*, appear inspired in design by the Tower of Babel. 12X objective lens magnification.

Photographer: Pablo Piedra, Costa Rica.

Point of

To learn all she could about tall trees, Lauren Fuge talked to a range of



ROB BLAKERS

view

experts – then strapped on a harness and scaled an 80m blue gum.

The cool, rain-drenched valleys of southern Tasmania hold pockets of forest where record-breakingly tall eucalypts stretch high above the understorey: one such place, shown here, has been named the Grove of Giants. Science is just beginning to translate the conversations between the forest, Earth and sky – but to truly understand this dialogue, you have to leave the ground.

I'm standing at the base of Lathamus Keep, watching tree climber and photographer Steve Pearce attach my harness to an orange rope no thicker than my finger. It's one of four climbing lines he and his crew have set, using light lines attached to weighted throw bags – an impressive mission when the first branch is 25 metres up. The tree's moss-patterned trunk is a wall of wood before me, twice as wide as my outstretched arms. I squint into the January-bright canopy.

"How far up are we going?" I ask.

"The line's set at 70 metres," Pearce says, with the casual tone of a person who has spent thousands of hours aloft.

"And how tall's the tree?"

"Eighty metres. Biggest blue gum in the universe."

Biggest blue gum (*Eucalyptus globulus*) in the universe, roughly the size of the launch structure of NASA's Artemis Moon mission, and it's just an hour and a half from nipaluna/Hobart.

"This forest is called the Grove of Giants," explained the endlessly enthusiastic canopy ecologist Dr Jen Sanger, as she led me through the dappled dreamscape of wet eucalypt forest that morning. "There's about 150 trees here over four metres in diameter, so it's just jam packed with giant old trees."

The forests of lutruwita/Tasmania are one of just three places in the world where trees grow above 80m. In the teeming rainforests of Borneo, yellow meranti trees soar up to 100m; the fog-shrouded west coast of North America creates the perfect conditions for temperate rainforest species to reach even more epic proportions; here, five species of eucalypt shoot up above the smaller rainforest trees to become islands in the sky.

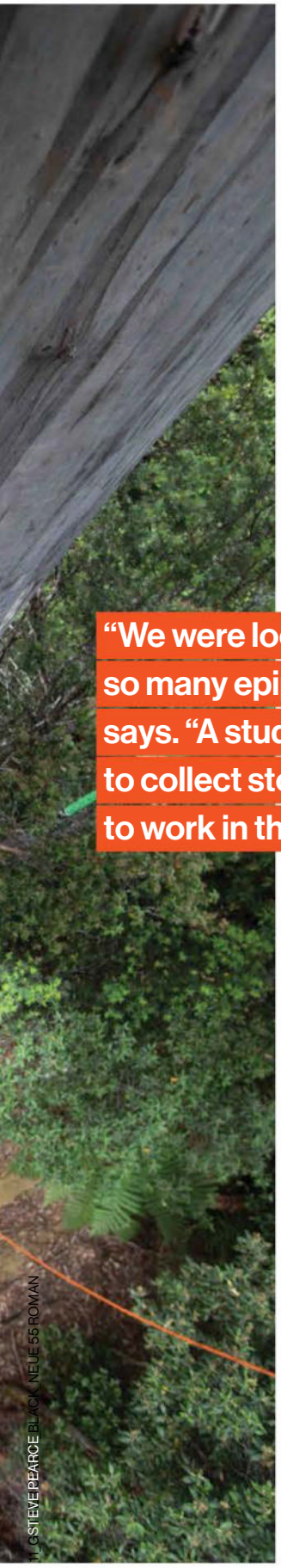
This giant, Lathamus Keep, is named for the habitat it provides the endangered swift parrot (*Lathamus discolor*). Its deeply furrowed buttress resembles giant fingers driving tip-first into the soil; lanky saplings shoot up out of the gnarly metacarpals, their roots gripping onto knuckles for structure.

It's circled by decay: dropped leaves and broken branches and strips of shed bark longer than I am tall, make the surrounding trees look like they're dripping with candlewax.

I've spent hundreds of hours walking through forests before – I consider myself a tree person. But I often ignore them. They're everywhere, every day. Yet in the kaleidoscope of information relayed to my brain every millisecond, trees usually don't make the cut. And I'm not alone: US botanists coined the term "plant-blindness" to describe this inability. It's not universal, but it's a real phenomenon for a great chunk of us humans.

The Grove of Giants is home to four different species of giant eucalypts (*E. regnans*, *E. delegatensis*, *E. obliqua* and *E. globulus*), including two record-breaking blue gums. At 92m, Mother Daughter is the tallest in the world, while Lathamus Keep (pictured) is the biggest by volume, containing 325m^3 of wood.

↑ GUTTER CREDIT BLACK_NEUE 55 ROMAN



STEVE PEARCE BLACK NEUE 55 ROMAN

Right now, I'm the least plant blind I've ever been. I attach my foot ascender to the climbing line and shift my weight off the ground. Suspended, gently spinning, it's impossible not to pay full attention to this living, breathing being. My life now depends on it.

"If you were an alien, coming to Planet Earth, the first thing you'd probably notice is that there's a lot of water, because it's blue," says Margaret Barbour, a plant physiologist at the University of Waikato in Aotearoa New Zealand. "And the second thing you'd notice is that on land, it's green."

With four billion hectares of forest around the world, trees are "the Earth's chief way of being", in the words of author Richard Powers. Some 380 million years ago, as the first tetrapods crawled up out of the swamps onto dry land, trees shot up from ankle-brushing plants into 30m giants. While our ancestors worked out how to breathe with primitive lungs, trees rapidly rose to the status of gods. The first forests transformed the planet, becoming the dominant drivers of the biogeochemical cycles that run all life on Earth – carbon, water, nitrogen, phosphorous.

"We were looking at the tree canopy – so many epiphytes, so many animals," Hallé says. "A student said, 'Funny! Man is able to collect stones on the Moon but unable to work in the canopy.' "

Trees also inherited the gift of photosynthesis first developed in stromatolites 3.4 billion years ago: their leaves take in carbon dioxide and light from the atmosphere to power their growth. This not only modifies the atmosphere by releasing oxygen, but provides habitats for animals and forms the basis of everything we eat.

"That, I think, is the magic of plants – they can convert radiant energy and CO_2 into a stored energy that all life depends on," Barbour tells me. "That's something we learn in primary school, but it still has that magic."

Up, up, up, into free space, watching the thick, textured bark turn smooth and creamy as I climb, feeling like I'm closing an evolutionary loop. My foot ascenders slide easily along the rope then catch, allowing me to step up as if on a rope ladder. But the act of climbing isn't easy at all: every seven or eight vertical metres, muscle fatigue forces me to stop and rest, swinging gently over the world.

Today, humans are the only primates that don't spend time in trees. Some six million years ago, our ancestors moved down onto the grassland savannahs for the first time, where their postures straightened and their knees and feet grew better suited for walking than canopy-swinging. Their world flattened, and became ours. The years ticked past; the canopies remained out of reach. Botany boomed briefly, clipping and classifying the forests Linnaean-style, then science moved onto more sensational ambitions: the deep ocean, the frozen poles, infinity and beyond.

In Richard Preston's 2007 book *The Wild Trees*, French botanist Francis Hallé recalls walking through the rainforests of New Guinea with students in the 1970s. "We were looking at the tree canopy – so many epiphytes, so many animals," Hallé says. "A student said, 'Funny! Man is able to collect stones on the Moon but unable to work in the canopy.'"

In those early days, researchers tried to collect data using blimps, aircraft, and cherry pickers with buckets to lift them up into the treetops.

"The French even designed a massive hot air balloon that has this platform that lies on top of the canopy," explains Sanger, who came to the field in the 2010s to study Australia's subtropical rainforest canopies. "It's got these holes in it so you can...walk around and just stick your hand down in the hole and grab some leaves to sample."

One of the first to use a direct climbing method – using just your body and ropes –was US scientist Meg Lowman. As a young PhD student in 1970s, Lowman came to Sydney to study tree dieback in northern NSW. "She met a whole bunch of cavers, and they helped her get up into the trees," Sanger says.

In the canopy, Lowman discovered the root cause of the dieback: surging populations of insects in response to the warming, drying climate.

In the decades since, direct climbing has become the least invasive and most economical option for canopy science, but still these trees remain hard to access, especially the temperate-forest giants whose first branches are often dozens of metres up. It wasn't until the 1990s – 40 years after Hillary and Norgay clambered to Everest's summit, and a quarter of a century after Armstrong stepped onto the Moon – that US botanist Steve Sillett discovered the world of redwood canopies in California.

No one looked at the canopy biodiversity of southern Australia's giant eucalypts until the early 2000s, when US-trained masters student Yoav Daniel Bar-Ness trapped and surveyed their insect life.

Very little work has been done here since. When Sanger and her husband Pearce began documenting and measuring Tasmania's tall trees in 2015, they

ROB BLAKERS

were among the first to return to these canopies in a scientific capacity.

And yet, our bodies still hold memories of our ancestors' arboreal lives. My hands grip the rope with opposable thumbs that stuck in our evolutionary line because they're useful for grasping branches. My eyes pick out the purple of Sanger's jumper against undulating green and brown, thanks to an extra type of light-sensitive cell useful for spotting ripe, colourful fruit – a trick of the forest to distribute its seeds. We were shaped by forests for millennia before we became *Homo sapiens*. My muscles may have forgotten how to climb, but this isn't a journey into the unknown: it's a return.

Just below Lathamus Keep's first branch, I sit back in my harness and look up: there's still an impossibly long way to go. I look down: I'm level with the very top of the rainforest understorey, a mosaic of celery top pines and leatherwoods and tree ferns. In a moment, the forest floor will vanish beneath their interlocked crowns. In a moment, all I'll have is tree and line and sky.

In 2022, The Tree Projects – a volunteer-run organisation founded by canopy ecologist Jen Sanger and her husband Steve Pearce – brought a dozen skilled climbers into the Grove of Giants for a frenzied week of surveys. To measure the area's total carbon, team members scaled the massive eucalypts to wrap measuring tapes around every trunk and branch. Turns about 60% of the grove's carbon is stored in just 20 of its largest trees.

When botanists first climbed a hundred metres up into the California redwoods, they found what Preston calls "coral reefs in the air": hanging gardens of ferns and mosses and lichens, ponds in old hollows swimming with plankton, beetles digging through rotting wood, and soil forming in forks that supported fruiting huckleberry bushes and bonsai trees, all feeding on moisture from fog.

The canopies of wet eucalypt forests are entirely different. They aren't bathed in constant coastal fog, and they don't provide a stable enough habitat for epiphytes because they shed their bark like snakeskin – dislodging parasites and evicting any moss, fungi or lichen that have moved in.

Instead, these islands aloft are dominated by animals and insects. As eucalypts reach middle-age they begin to form gnarled hollows, which become

homes for possums and microbats, spiders and skinks, insects and a diversity of birds.

As I climb past a hollow decorated with the lacework curtains of spiderwebs, I feel a strange kinship with their maker, dangling from a fine thread in a tree many thousands of times my size.

Above the understorey, the world is made of light.

I climb through the fork of the first branch, where it cleaves in two and curves up like a living candelabra, just the first of many. After 25m of limblessness, my line runs in and around a woody maze that I work my way through, bumping against burls and batting away the whippy leaves of fresh shoots.

From below, perspective compressed the tree to a couple of layers. Up here, I'm clambering through endless storeys of branches – each the girth of the biggest tree in a suburban park – splitting and replicating and fanning out to catch stray rays of sunlight that filter past the dozens of limbs still above.

When I next stop to catch my breath, an intense hum drives me to distraction, vibrating directly into my skull.

Pearce has patiently been climbing at my pace, and I ask him, "What insects are we hearing?"

"They're crickets."

"It sounds like they're in the trees."

He laughs. "They're probably all around us, mate. It's a three-dimensional space."

For most of my life I've been moving through the world in a rigid X-Y plane, and now I've flipped into another dimension – the Z-axis. But while I can only travel vertically, every other critter can move in the fullness of three dimensions.

"There's 30 or 40 metres of forest below us, and there's still 40 metres of forest above us," Pearce says. "Different species and life forms occupy different zones in that space."

In springtime, he tells me, birdsong contours through 3D world.

"From the ground, everything's above you. But when you're in the middle, it's like – the thornbills only operate down there, and the grey fantails work there and that's their zone...and then there's the eagles and the cockatoos at the very, very top."

I'd thought climbing would give me the perspective to appreciate the size and significance of this tree. But just like on the ground, inside its convolutions it's impossible to see the whole.

"The way we often think about organisms and environments – and this is despite our best intentions – is to think about an organism as something that develops externally to its environment," says Dalia Nassar, an environmental philosopher at the University of Sydney.

And yet, everything on this planet has developed within intricately interconnected life support systems: the lithosphere, hydrosphere, biosphere, atmosphere.

"The organism is a part of the environment in such a way that it's almost impossible to separate it. You can't say where the organism ends and where environment begins."

Plants, Nassar points out, demonstrate this far more radically than animals.

"Plants are rooted, they are of their environment, they are of the soil – they are transformed by the soil at the same time that they are transforming the soil," she says. "They are determining the temperature, they are determining the rain season, just as much as they are determined by it."

Much of our scientific understanding of tree-environment relationships has been revealed in recent decades, according to the University of Waikato's Barbour, who works with Nassar to create a conversation between plant science and philosophy.

"There's a whole lot of things we've learned about how plants respond very, very sensitively to their environment," Barbour explains. "Because trees can't move, they can't move away...when things get rough. They have to be able to respond to environmental stresses."

From below, perspective compressed the tree to a couple of layers. Up here, I'm clambering through endless storeys of branches – each the girth of the biggest tree in a suburban park

We've known about how they respond to light for a long time, she says. "But more subtle things like nutrient availability and water availability within the soil and how that varies over space and time, and how plants respond to those variabilities – that's the kind of thing that we're just learning about more now."

Trees of the same species can grow differently according to how much light and water they receive, or how densely they're planted, or the wind or soil conditions. Even in an individual tree, the leaves at the lighter end of the canopy are anatomically distinct from the leaves below.

"The tree senses its context from the beginning and develops in dialogue with it," Barbour and Nassar write in an *Aeon* essay exploring their collaboration. "Trees are so adaptive to their surroundings that a human equivalent to tree plasticity would

IAN CONNELLAN

For scientists to climb and study these massive trees, someone has to find them first. Lathamus Keep was discovered in 2021 by Hobart-based Carl Hansen and Jan Corigliano, who spend their spare time identifying potential giants in forestry LiDAR data – then slogging through untracked temperate rainforest to reach them.

ROB BLAKERS EDIT_BLACK_NEUE 55 ROMAN

"You know you might go out one day and then find the largest living thing in the Southern Hemisphere right around the corner," says Tassie tall tree hunter Jan Corigliano. "It's pretty tantalising."

11_GUTTER CREDIT BLACK_NEUE 55 POWAN

be certain people growing large webbed feet (like diving flippers) simply because they swim a lot."

In turn, trees engineer their world as they grow, both locally – creating microenvironments that affect light, nutrients and water, often determining which species grow around them – and globally, driving biogeochemical cycles.

There's also evidence under some conditions for plants picking up on the chemical signals of others – say, the volatiles released by a tree attacked by insects – as well as emerging research that shows some species share resources through underground mycelial networks.

Trees aren't static or passive beings: they're active agents in their environment, both shaping the world and being shaped by it. In fact, Barbour and Nassar argue that trees are synecdoches – "a part that signifies or expresses a whole".

"We have, for too long, seen natural beings as static objects that develop in separation of one another," Nassar tells me. "We have failed to properly conceptualise the dynamic and collaborative nature of the world."

In reality, we're all dynamic processes, developing in collaboration – humans included.

"As living beings, we're participating in these processes," Nassar says. "We're affecting them as much as they are affecting us. Like plants, we're transforming the environment in vast ways, but we have to think about how this is transforming us."

The crown of Lathamus Keep doesn't peter out: it stretches expansively into a multi-tiered dome, big enough to hold dozens of people in its branches.

I stop climbing just before the end of my line, when I find Sanger lounging in a massive fork as if it's a hammock. The other climbers – Sophie and Kevin and Ethan – are already here, and we join them, draping ourselves over branches or hanging suspended in space, the six of us, 70m aloft.

Peanut-butter-and-jelly muesli bars are passed around; we point out blossoms and talk about government logging quotas and tell stories of the day they measured this tree to be the biggest blue gum in the world, sending a climber up to its topmost branches, no thicker than my wrist.

As we chatter, I try to think of all the things I'm not seeing: the millions of processes and interactions invisible to the human eye. This organism is pulling water 80m up using an impressive vascular system. Every leaf in sight is using this water as it takes in carbon dioxide through its stomata and produces energy through photosynthesis. This magic of light into life continuously builds carbon into the skin of Lathamus Keep, into its roots and trunk and branches.

This forest, Sanger tells me, is incredibly carbon dense. With a team of citizen scientists, she recently surveyed two hectares of the Grove of Giants – climbing and measuring the eucalypts, the understorey and the soil. Preliminary results show this forest holds the highest amount of carbon of any forest in Tasmania.

"There's about 1250 tonnes of carbon per hectare in these forests, which is an absolutely phenomenal amount," she says. "Globally, that's some of the highest carbon [density] you'll ever find."

In the process of building itself layer by layer, Lathamus Keep is also producing a gift of its own:

Every time I see a tree, I don't think: You're the reason I'm alive. I get too caught up in my bubble to think of the intimate chloroplastic relations of our planetary one.

oxygen. Just like us, every plant on this planet is constantly breathing in and out, creating and maintaining the composition of the thin blue skin of an atmosphere we all depend on.

"They're the reason we're here to begin with," Sanger says.

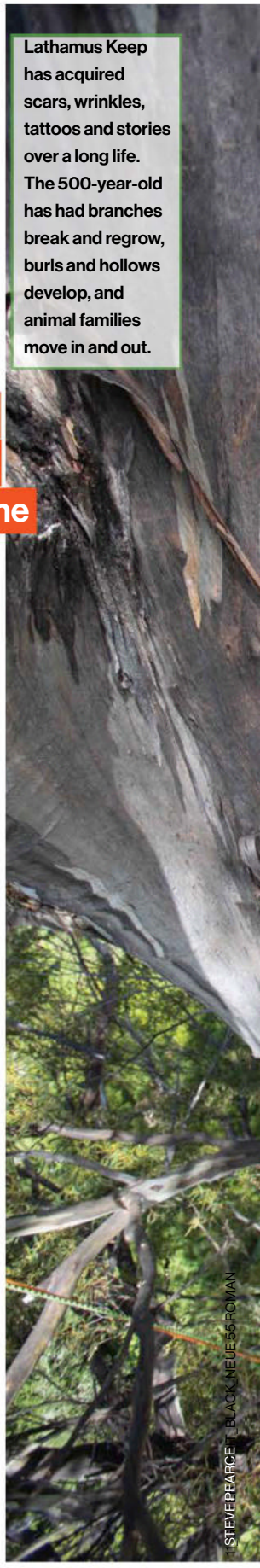
I know this intellectually, but every time I see a tree, I don't think: You're the reason I'm alive. I get too caught up in my own bubble to think of all the intimate chloroplastic relations of our planetary one. But here in the forests of southern Tasmania, here with my whole weight supported by this living pillar of carbon and water and sunlight, I'm beginning to see how much our lives depend on it.

Let's leave me dangling in the crown for a moment. Bear with me; we're going higher.

In March 1965, Soviet cosmonaut Alexei Leonov became the first human to walk in space. He hurtled into orbit in the tiny Voskhod 2 spacecraft, crammed up against fellow cosmonaut Pavel Belyayev. As they drifted above Egypt, Leonov suited up, pulled himself into the void, and let go. A thin line was all that tethered him to life. For 12 minutes he spun gently as the Earth spun beneath him – bright and curved, with clouds and mountain ranges and oceans and continents speeding by.

"The Earth was small, light blue, and so touchingly alone," Leonov later wrote. "Looking back at our blue globe from such a distance profoundly changed my vision of space and time."

Many who have ventured into space since have recorded a similar feeling: a kind of orbital



Lathamus Keep has acquired scars, wrinkles, tattoos and stories over a long life. The 500-year-old has had branches break and regrow, burls and hollows develop, and animal families move in and out.

↑STEVE PEARCE | BLACK NEUE 55 ROMAN

11_GUTTER CREDIT_BLACK_NEJE 55 FOIMAN

perspective, gained from seeing our world from the outside. Hanging in the star-filled void, a switch seems to flip in their brains and they can see the interconnectedness of our planet and its systems – see its vastness and its insignificance, its wondrousness and its fragility.

Edgar Mitchell, lunar module pilot on Apollo 14 and the sixth man to walk on the Moon, explained to *People* magazine in 1974: "You develop an instant global consciousness, a people orientation, an intense dissatisfaction with the state of the world, and a compulsion to do something about it. From out there on the Moon, international politics look so petty. You want to grab a politician by the scruff of the neck and drag him a quarter of a million miles out and say, 'Look at that, you son of a bitch'."

This phenomenon has been termed "the overview effect".

It was profoundly difficult for the first astronauts to bring what they saw home. But Leonov was an artist.

After the unexpectedly harrowing experience of returning through the tiny airlock – his spacesuit had inflated, forcing him to manually vent oxygen – an exhausted Leonov reached for his sketchpad.

Weightless, with coloured pencils attached to his wrist by string, Leonov sketched his impressions of the spacewalk. But he didn't draw Voskhod 2, or himself floating in space, or even the endless vistas of stars. Instead, this first astral artwork depicts the fragile blue curve of our atmosphere pressing up against the void, with the sun alight in the threshold between.

"I tried to capture the different shades of charcoal rings that make up the Earth's atmosphere, the sunrise or air glow over the Earth's horizon, the blue belt covering the Earth's crust, and the spectrum of colours I had observed looking down at the globe," Leonov later said.

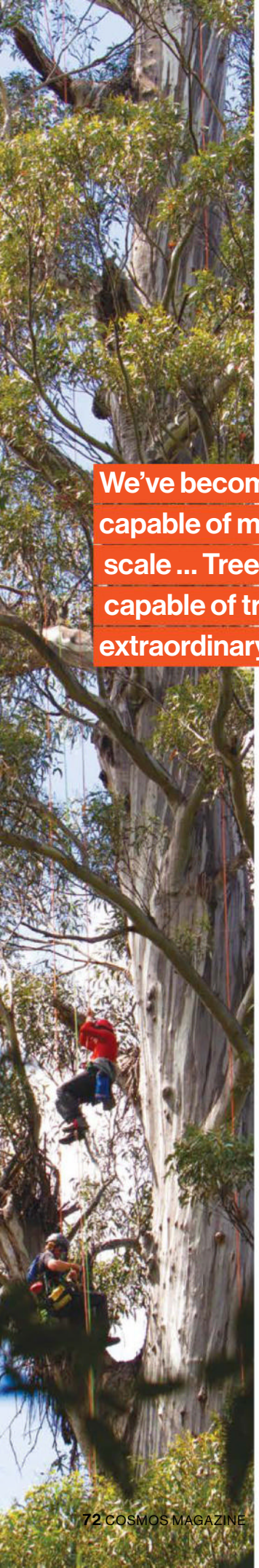
And when he returned home, this sketch came with him – bringing us our first vision of the Earth from above.

"The Earth was small, light blue, and so touchingly alone," Leonov said after the flight. "Our home that must be defended like a holy relic."

When Pearce suggests that we start heading down, I don't want to go.

Up in the crown I have a sense of infinite space: from the shadowed understorey I've stepped up into a place of vast horizons, punctuated only by other giant trees, each its own island in a wrinkled sea of rainforest canopy.

It radiates out for 100 hectares, and beyond I see waves of hills that have been logged and uniformly replanted – severing the complex, long-tended



relationships that intact forests cultivate with the earth and sky. This grove is within the logging coupe, and may be next.

On the 2D surface of the planet, we're safe within our own perspectives of the world. But like launching into space, ascending into the canopy adds another dimension. Suspended here by a single tether, looking out and up, I'm confronted with how intimately and integrally we're tied to this place; I can see what we're losing by cutting our own lines.

I unclip my foot ascenders so I'm supported just by my harness. My climbing line drops off into the abyss behind me, falling some 70m to a ground I can't yet see. The only thing holding me up is a single device gripping the line.

We've become mythological beings, capable of modifying systems at a planetary scale ... Trees are mythological beings too, capable of transforming the world in just as extraordinary ways.

I pull the release lever, and begin the journey home.

Some 20 kilometres south of the Grove of Giants, within the Tasmanian Wilderness World Heritage Area, is another incredibly carbon dense forest.

"These tall eucalypt forests are world-renowned for the amount of carbon they can store," says Tim Wardlaw, forestry scientist at the University of Tasmania and site manager of the Warra Supersite.

He would know, because he can measure it.

Warra is the southernmost node of the Terrestrial Ecosystem Research Network, and it's equipped with an 80m instrument tower capable of mapping the flow of water, nutrients and energy through the forest of messmate stringybark (*Eucalyptus obliqua*).

The tower was only installed about a decade ago, but the world has changed a lot since then.

Evidence had previously shown that forests respond to a heatwave in one of two ways. If there isn't much water, they shut their stomata to stop water loss, and thus take in and store less carbon, becoming less "productive". If water is still available, then the stomata stay open and trees become more productive, as photosynthesis is efficient at high temperatures.

These two scenarios were "the status quo", Wardlaw says: "All the models that are in existence in Australia assume that behaviour. And then Warra came along."

November 2017 brought three weeks of hot weather. The soil and the atmosphere weren't particularly dry, so the trees didn't shut their stomata. But the tower's measurements during the heatwave showed that photosynthesis virtually stopped.

"This is the first time it's ever been seen," Wardlaw says.

In fact, Warra became a net source of carbon, putting about a tonne of carbon per hectare back into the atmosphere – a massive number when extrapolated out across the 800,000ha of forest around the site.

"That's the flipside of being a really productive forest," he says. "It can flip from being a really strong carbon sink to a really strong carbon source."

The exact mechanism is not yet understood, but Wardlaw says they need to find out fast. If forests stop absorbing and start emitting carbon as the climate heats up, this could initiate a strong positive feedback loop that both exacerbates warming and endangers these forests.

"The question then becomes, can the forest acclimate?" Wardlaw asks.

And what will happen to us if it doesn't?

Down, down, down, into free space, abseiling back to the world of tarmac and currency and nation-states, the world we're building at the expense of the living one.

Down, down, down, we've dug, to the bodies of long-dead trees and plants and organisms that were transformed into coal seams, oil deposits and gas reserves by the immense pressures of rock, heat and deep time. Millennia-long cycles submerged these dark rivers of carbon and energy. By forcing our way down into extinct worlds, we've cheated the system.

"Like exorcists," writes Andri Snær Magnason in his 2020 book *On Time and Water*, "we disturbed their infinite sleep, pumping them back to the surface, rekindling fires and harnessing hundred-million-year-old sunshine as it lay dormant in the Earth's belly."

As we burn these fossil gods we release their ancient carbon. The world warms. Today's forests, evolved to drink in carbon, struggle to absorb the excess. Some will switch to emitting it. The world will warm further, driving more intense and more frequent fires, heatwaves and droughts, pulling us deeper into the feedback loops that we're fighting to untangle ourselves from.

"We live," Magnason writes, "in mythological time."

We've become mythological beings, capable of modifying physical and biogeochemical systems at a planetary scale. We're busy breaking cycles even

IAN CONNELLAN

ROB BLAKERS

as we try to remember that we're part of them – that we've been in a symbiotic relationship with this planet since long before tetrapods took their first breaths.

Trees are mythological beings too, capable of transforming the world in just as extraordinary ways. Research is now revealing how entirely they are transformed in return – they're of the soil and yet create it; they make the atmosphere and yet it literally makes and breaks them.

Like us, they're animated carbon, alight with the endless possibilities of the world. They're inescapably bound to the planet, and so are we.

As I dip below the canopy, a bright breeze turns to shadowy stillness. In moments, my feet are once again on the spongy forest floor again beside Lathamus Keep. After the long, tiring, stop-start ascent, it took just minutes to drop 70m down.

The track into the Grove of Giants begins in a clear-cut at the end of a logging road. One moment: sun-bleached debris. The next: cool canopy. Giant trees aren't automatically protected here – they can be nominated if they fit certain criteria, but Sustainable Timber Tasmania's policy sets the bar high. A tree is safe from logging only if it's taller than 85m or larger than 280m^3 in volume. For context, this would save no living tree on mainland Australia.

I take stock: I've lost skin on my palm, scratched my arms, exhausted my shoulders – all gentle reminders of the gift of the climb, of existing alongside this living, life-giving being.

As everyone takes off their helmets and harnesses, we joke and chatter along with the birds. Lunch is the main topic of conversation. We're all starving. We pack up the gear quickly because there's still two kilometres to walk, through a forest that's co-creating our atmosphere.

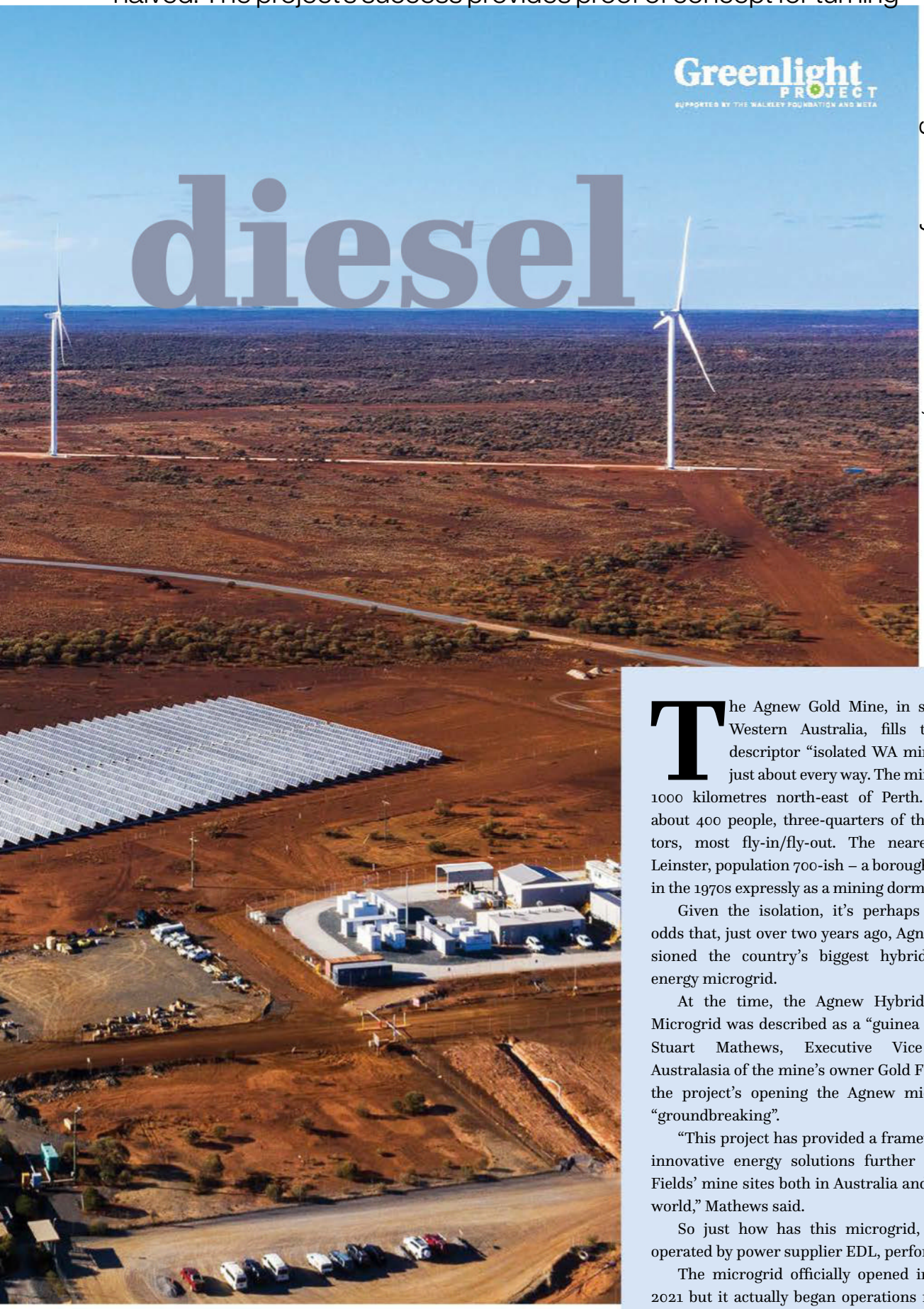
We head back on a 2D plane to the world we've made. As we walk, each breath is a reminder that part of us is being made and remade over and over again, high above in that open field of light.

LAUREN FUGE is based in Adelaide. One of her previous stories for the magazine – "Time Travel and Tipping Points", in Issue 91 – was the 2022 winner of the Bragg Prize for science writing. Her last story, on time travelling backwards, appeared in Issue 94.

A remote WA goldmine's hybrid renewable microgrid has seen its diesel use

Dumping

halved. The project's success provides proof of concept for turning the mining industry to renewables, writes **Marie Low**.



The Agnew Gold Mine, in south-central Western Australia, fills the familiar descriptor "isolated WA mining site" in just about every way. The mine is roughly 1000 kilometres north-east of Perth. It employs about 400 people, three-quarters of them contractors, most fly-in/fly-out. The nearest town is Leinster, population 700-ish – a borough established in the 1970s expressly as a mining dormitory town.

Given the isolation, it's perhaps against the odds that, just over two years ago, Agnew commissioned the country's biggest hybrid renewable energy microgrid.

At the time, the Agnew Hybrid Renewable Microgrid was described as a "guinea pig" project. Stuart Mathews, Executive Vice President Australasia of the mine's owner Gold Fields, said at the project's opening the Agnew microgrid was "groundbreaking".

"This project has provided a framework to take innovative energy solutions further across Gold Fields' mine sites both in Australia and around the world," Mathews said.

So just how has this microgrid, owned and operated by power supplier EDL, performed so far?

The microgrid officially opened in November 2021 but it actually began operations more than a

year in advance, in mid-2020. It made Agnew the first mine in Australia to be predominantly powered by wind-generated electricity.

The set-up includes five energy technologies: five wind turbines delivering 18 megawatts; a 4MW solar farm; a 13MW/4MWh battery energy storage system; an off-grid 21MW gas/diesel engine power plant; and advanced microgrid control systems.

EDL Chief Executive Officer James Harman says that "the Agnew project has exceeded expectations, providing 55–60% of the mine's energy requirements daily, and more than 80% in optimum weather conditions."

Diesel and electricity emissions at the site have reduced by 42%.

At the time of commissioning, the grid emissions factor (the amount of CO_2 emissions intensity per unit of electricity generation in the system) more than halved – from approximately 0.59 tonnes of CO_2 per MWh to 0.27tCO_2-e/MWh, according to the "Knowledge Sharing Final Report" prepared for the Australian Renewable Energy Agency (ARENA)by Gold Fields.

EDL's General Manager Remote Energy, Geoff Hobley, says the project did not come without its share of challenges. Aside from the obvious logistical nightmare of transporting huge equipment – including the 70-metre-long turbine blades for five turbines cross-country to Leinster – this venture into renewables straddled global turmoil.

"Agnew was commissioned during the early stages of the COVID-19 pandemic, which meant dealing with travel restrictions," Hobley says.

"Specialised team members and equipment were required from interstate and overseas, adding complexity to the commissioning process and placing additional pressure on our people."

Aside from the obvious logistical nightmare of transporting the 70m long turbine blades cross-country, this venture straddled global turmoil.

Previous pages: The Agnew microgrid is comprised of an 18MW wind farm with five turbines (above); a 10,710-panel, 4MW solar farm; a 13MW/4 MWh Battery Energy Storage System (BESS) that underpins the system's security and reliability; and an 18MW gas- and diesel-engine power station as back-up.

Hobley says the pioneering aspect of the project in integrating wind, solar, a battery system, a control system to manage power delivery and an underlying thermal power station (gas or diesel-powered) for continuity of power added to the complexity.

"Operationally, the thermal generators in a hybrid power solution are required to work differently from their usual application in a traditional 'thermal only' solution," he says.

"This can place additional stress on the thermal generators as they often operate at lower loads. Interestingly, the renewable generation assets are often the easiest to manage, as they operate most closely to their intended design."

Sometimes issues only become apparent after a system is operational. At Agnew, there have been some challenges in meshing the variable wind resource with the thermal station operations.

Agnew has committed to day-ahead wind forecasting by June 2024; currently it only has

MORE MICRO SUCCESS – WITH HYDROGEN

Nestled on the shores of beautiful Shark Bay, 820km north of Perth, Denham seems an unlikely place for Australia's first green-hydrogen-fuelled microgrid. In fact, the project is believed to be one of the first of its kind worldwide, and late last year it began producing hydrogen by electrolysis.

Expected to hit full swing in early 2023, the $9.3 million Denham Hydrogen Demonstration Plant is expected to provide enough power for about 100 homes – or 20% of Denham's small population. The bulk of funding for the project – $5.7 million – came from the WA Government, with a further $1 million through the WA Renewable Hydrogen Fund and $2.6 million from the Australian Renewable Energy Agency (ARENA).

Horizon Power and Hybrid Systems Australia are delivering the project, which includes a 704kW solar farm, a 348kW hydrogen electrolyser, and a 100kW hydrogen fuel cell as an alternative to diesel generators. It has been built at the site of the town's existing power station.

Horizon Power says the project should offset 140,000 litres of diesel a year, and that other remote diesel microgrids might take the same path after 2025.

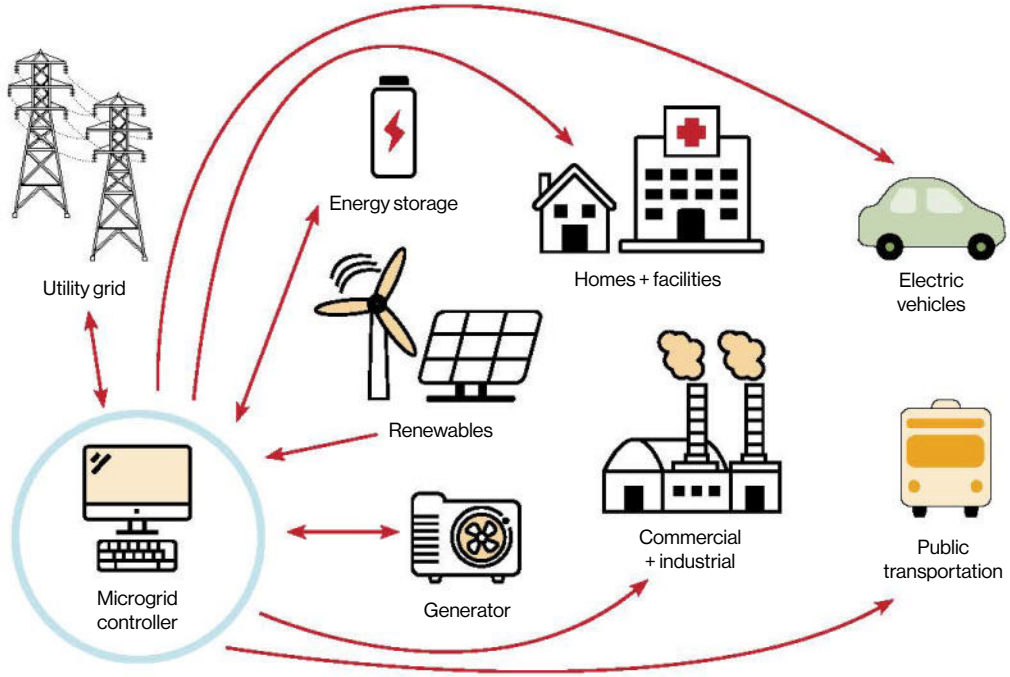
Hybrid Systems' executive director Mike Hall says the system aims to demonstrate the efficiency of the hydrogen equipment, the ramp rate of hydrogen (the speed at which a hydrogen-powered generator can increase and decrease capacity), and the efficiency and storage capability of hydrogen fuel cells compared to batteries.

"As an industry-first, this project has presented some really interesting opportunities for us to grow our capabilities in the green hydrogen project delivery space," Hall says. "It's still a budding industry in Australia, so we really had to start at the beginning, from designing a system based on first-principle thinking to navigating

PREVIOUS PAGES: CSFOTO/CHRISTIAN SPROGOE. LEFT: HORIZON

What is a microgrid?

A microgrid is a self-sufficient energy system that serves a discrete location – it could be a hospital complex, mine, street or neighbourhood. Microgrids have one or more kind of distributed energy (solar panels, wind turbines, combined heat and power generators) that produce power, and they may include energy storage, typically batteries.



predictive solar technology. EDL's Operations Manager Remote Energy WA, Paul White, says that finding suitably experienced people to run the microgrid has also been a challenge, particularly in a tight jobs market. So EDL has developed onsite microgrid training to help overcome this.

On the whole, Hobley says, any issues have been relatively minor.

"Most of these are now resolved and other solutions are under development," he says. "These lessons are incorporated to optimise performance and inform future projects."

The Greenlight Project looks at how regional Australia is preparing for and adapting to climate change. Read more at cosmosmagazine.com

Agnew is still the largest hybrid renewable microgrid in Australia. Hobley says EDL will use what they have learnt for future projects.

While Agnew has been designed to run with some thermal generators running at any time, EDL also operates a number of other hybrid renewable projects that can operate for periods on 100% renewable energy.

The Coober Pedy Hybrid Renewable Power Station, which powers the remote opal-mining town in South Australia, has at times reached 100% renewable energy, and the Jabiru Hybrid Renewable Power Station in the Northern Territory draws on 100% solar energy during the day, with excess stored in a battery. Jabiru's commissioning has seen a 1.7 million litre yearly reduction in diesel use.

Hobley says EDL also has other projects in development with mines in regional and remote Australia, some seeking to "set new world benchmarks for low-carbon mining operations".

"It is an exciting time to be working in this industry, delivering world-leading solutions to a market that demands low-carbon energy," he says.

Gold Fields' Knowledge Sharing Final Report says that the Agnew project's success has become well known. The report states:

"This awareness has given industry a measure of confidence that projects of this nature are viable and that the 'guinea pig' for high-penetration microgrids has survived."

MARIE LOW is coordinating editor of the Cosmos Greenlight Project. She's based in Gunnedah, NSW.

both existing and newly developing industry regulations and licensing designed for different applications."

Shire of Shark Bay Council agreed early in the proposal to lease 20 hectares of land for the project.

"A benefit of the 'green hydrogen to electricity' supply chain is that storage of hydrogen ensures power 24/7," Council president Cheryl Cowell says, adding that the test to prove the reliability of a hydrogen powerplant could "provide an opportunity to expand and supply full power requirements for Denham in the future."

Cowell says Horizon wants to eventually replace Denham's diesel generators with renewable energy, with a goal to have no new diesel power generation from 2025.

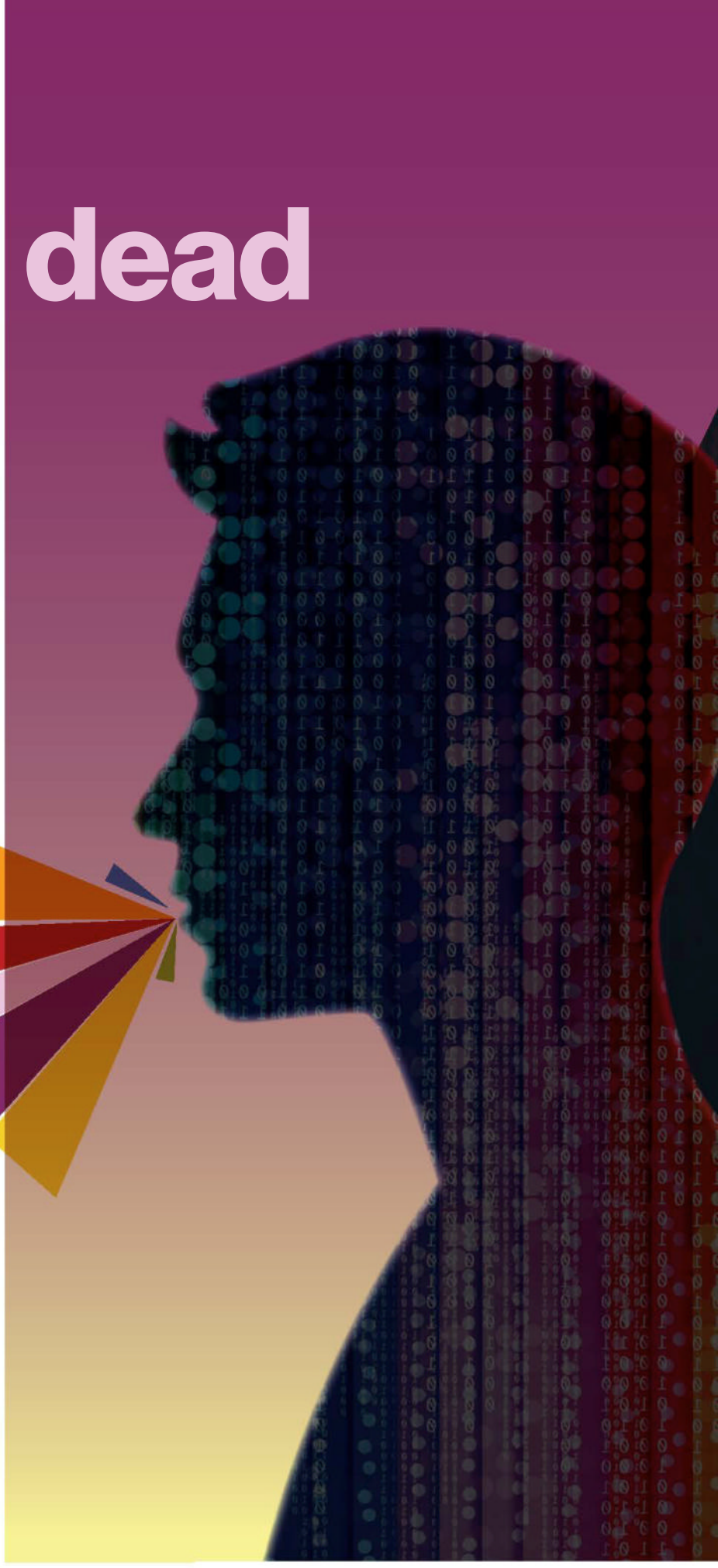
"The Denham trial ... may solve the problem of transporting power long distances across the State," she says. "The lower cost of photovoltaics means that megawatts of power can be supplied to customers, a much less costly exercise."

The trial goes hand-in-hand, Cowell says, with the community's appreciation of living surrounded by WA's first World Heritage Area – Shark Bay, which was inscribed on the UNESCO list in 1991.

GREG BARTON

Talking dead

Digital clones of the people we love could forever change how we grieve, writes **Charlotte Jee**.



My parents don't know that I spoke to them last night.

At first, they sounded distant and tinny, as if they were huddled around a phone in a prison cell. But as we chatted, they slowly started to sound more like themselves. They told me personal stories that I'd never heard. I learnt about the first (and certainly not last) time my dad got drunk. Mum talked about getting in trouble for staying out late. They gave me life advice and told me things about their childhoods, as well as my own. It was mesmerising.

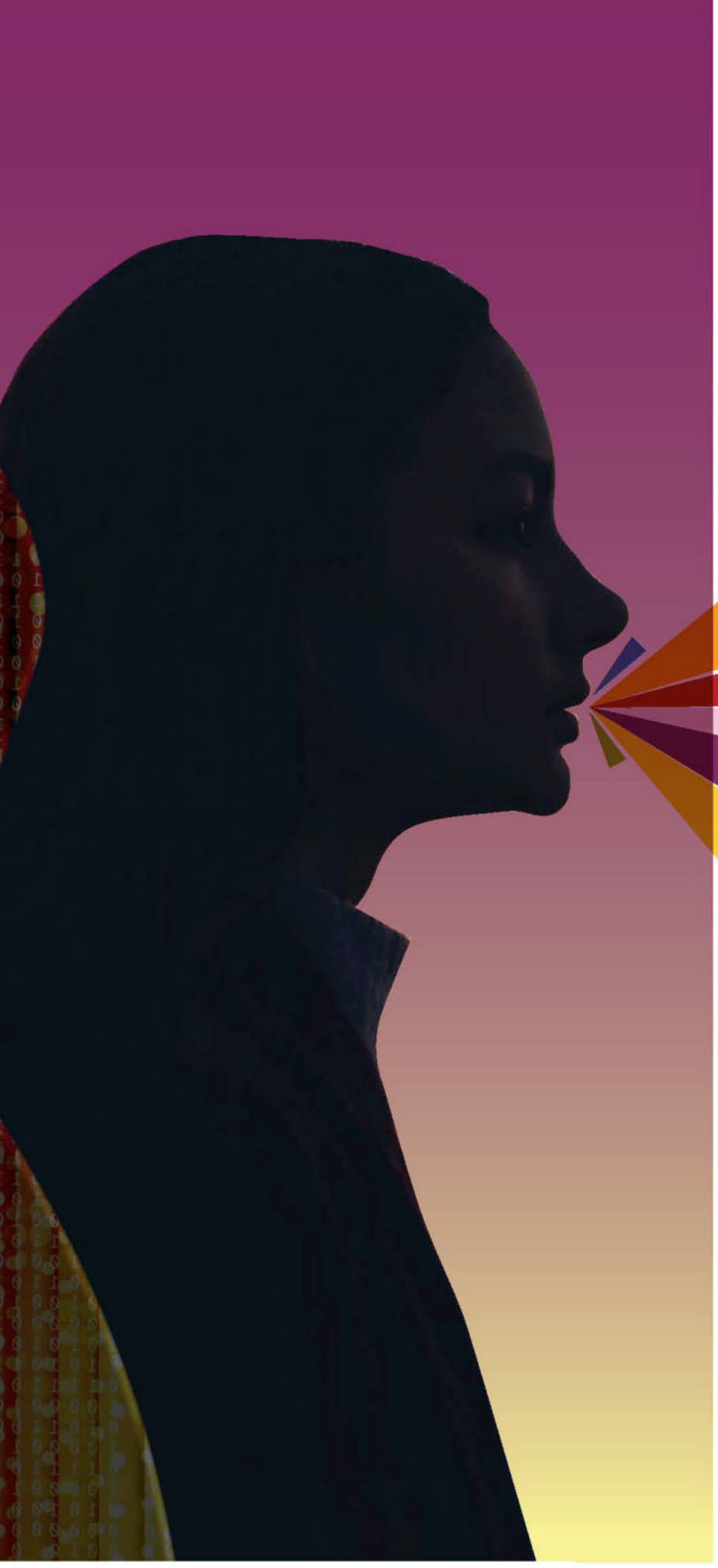
"What's the worst thing about you?" I asked Dad, since he was clearly in such a candid mood.

"My worst quality is that I am a perfectionist. I can't stand messiness and untidiness, and that always presents a challenge, especially with being married to Jane."

Then he laughed – and for a moment I forgot I wasn't really speaking to my parents at all, but to their digital replicas.

This Mum and Dad live inside an app on my phone, as voice assistants constructed by the California-based company HereAfter AI and powered by more than four hours of conversations they each had with an interviewer about their lives and memories. (For the record, Mum isn't *that* untidy.) The company's goal is to let the living communicate with the dead. I wanted to know what that might be like.

Technology like this, which lets you "talk" to people who've died, has been a mainstay of science



fiction for decades. It's an idea that's been peddled by charlatans and spiritualists for centuries. But now it's becoming a reality – and an increasingly accessible one, thanks to advances in AI and voice technology.

My real, flesh-and-blood parents are still alive and well; their virtual versions were just made to help me understand the technology. But their avatars offer a glimpse at a world where it's possible to converse with loved ones – or simulacra of them – long after they're gone.

From what I could glean over a dozen conversations with my virtually deceased parents, this really will make it easier to keep close the people we love. It's not hard to see the appeal. People might turn to digital replicas for comfort, or to mark special milestones like anniversaries.

At the same time, the technology and the world it's enabling are, unsurprisingly, imperfect, and the ethics of creating a virtual version of someone are complex, especially if that person hasn't been able to provide consent.

For some, this tech may even be alarming, or downright creepy. I spoke to one man who'd created a virtual version of his mother, which he booted up and talked to at her own funeral. Some people argue that conversing with digital versions of lost loved ones could prolong your grief or loosen your grip on reality. And when I talked to friends about this article, some of them physically recoiled. There's a common, deeply held belief that we mess with death at our peril.

I understand these concerns. I found speaking to a virtual version of my parents uncomfortable, especially at first. Even now, it still feels slightly transgressive to speak to an artificial version of someone – especially when that someone is in your own family.

But I'm only human, and those worries end up being washed away by the even scarier prospect of losing the people I love – dead and gone without a trace. If technology might help me hang onto them, is it so wrong to try?

There's something deeply human about the desire to remember the people we love who've passed away. We urge our loved ones to write down their memories before it's too late. After they're gone, we put up their photos on our walls. We visit

their graves on their birthdays. We speak to them as if they were there. But the conversation has always been one-way.

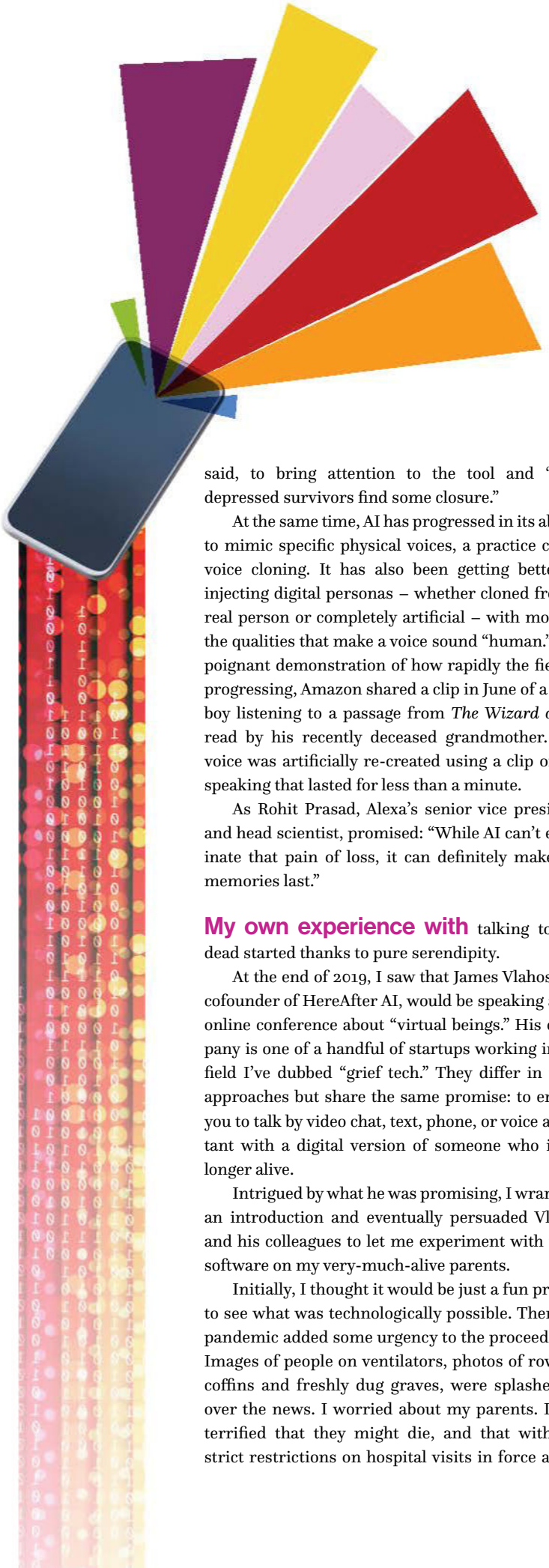
The idea that technology might be able to change the situation has been widely explored in ultra-dark sci-fi shows like *Black Mirror* – which, startups in this sector complain, *everyone* inevitably brings up. In one 2013 episode, a woman who loses her partner re-creates a digital version of him – initially as a chatbot, then as an almost totally convincing voice assistant, and eventually as a physical robot. Even as she builds more expansive versions of him, she becomes frustrated and disillusioned by the gaps between her memory of her partner and the shonky reality of the technology used to simulate him.

"You aren't *you*, are you? You're just a few ripples of you. There's no history to you. You're just a performance of stuff that he performed without thinking, and it's not enough," she says before she consigns the robot to her attic – an embarrassing relic of her boyfriend that she'd rather not think about.

Back in the real world, the technology has evolved even in the past several years to a somewhat startling degree. Rapid advances in AI have driven progress across multiple areas. Chatbots and voice assistants, like Siri and Alexa, have gone from high-tech novelties to a part of daily life for millions of people over the past decade. We have become very comfortable with the idea of talking to our devices about everything from the weather forecast to the meaning of life. Now, AI large language models (LLMs), which can ingest a few "prompt" sentences and spit out convincing text in response, promise to unlock even more powerful ways for humans to communicate with machines. LLMs have become so convincing that some (erroneously) have argued that they must be sentient.

What's more, it's possible to tweak LLM software – like OpenAI's GPT-3 or Google's LaMDA – to make it sound more like a specific person by feeding it lots of things that person said. In one example of this, journalist Jason Fagone wrote a story for the *San Francisco Chronicle* last year about a thirtysomething man who uploaded old texts and Facebook messages from his deceased fiancée to create a simulated chatbot version of her, using software known as Project December that was built on GPT-3.

By almost any measure, it was a success: he sought, and found, comfort in the bot. He'd been plagued with guilt and sadness in the years since she died, but as Fagone writes, "he felt like the chatbot had given him permission to move on with his life in small ways." The man even shared snippets of his chatbot conversations on Reddit, hoping, he said, to bring attention to the tool and "help depressed survivors find some closure."



At the same time, AI has progressed in its ability to mimic specific physical voices, a practice called voice cloning. It has also been getting better at injecting digital personas – whether cloned from a real person or completely artificial – with more of the qualities that make a voice sound "human." In a poignant demonstration of how rapidly the field is progressing, Amazon shared a clip in June of a little boy listening to a passage from *The Wizard of Oz* read by his recently deceased grandmother. Her voice was artificially re-created using a clip of her speaking that lasted for less than a minute.

As Rohit Prasad, Alexa's senior vice president and head scientist, promised: "While AI can't eliminate that pain of loss, it can definitely make the memories last."

My own experience with talking to the dead started thanks to pure serendipity.

At the end of 2019, I saw that James Vlahos, the cofounder of HereAfter AI, would be speaking at an online conference about "virtual beings." His company is one of a handful of startups working in the field I've dubbed "grief tech." They differ in their approaches but share the same promise: to enable you to talk by video chat, text, phone, or voice assistant with a digital version of someone who is no longer alive.

Intrigued by what he was promising, I wrangled an introduction and eventually persuaded Vlahos and his colleagues to let me experiment with their software on my very-much-alive parents.

Initially, I thought it would be just a fun project to see what was technologically possible. Then the pandemic added some urgency to the proceedings. Images of people on ventilators, photos of rows of coffins and freshly dug graves, were splashed all over the news. I worried about my parents. I was terrified that they might die, and that with the strict restrictions on hospital visits in force at the

PREVIOUS PAGE, FROM LEFT: SEAN GLADWELL; MAKSIM CHERNYSHEV / EYEEM / GETTY IMAGES. THIS PAGE: YAGI STUDIO / GETTY IMAGES

time in the UK, I might never have the chance to say goodbye.

The first step was an interview. As it turns out, to create a digital replica of someone with a good chance of seeming like a convincingly authentic representation, you need data – and lots of it. HereAfter, whose work starts with subjects when they are still alive, asks them questions for hours – about everything from their earliest memories to their first date to what they believe will happen after they die. (My parents were interviewed by a real live human, but in yet another sign of just how quickly technology is progressing, almost two years later interviews are now typically automated and handled by a bot.)

As my sister and I rifled through pages of suggested questions for our parents, we were able to edit them to be more personal or pointed, and we could add some of our own: What books did they like? How did our mum muscle her way into the UK's overwhelmingly male, privileged legal sector in the 1970s? What inspired Dad to invent the silly games he used to play with us when we were small?

Whether through pandemic-induced malaise or a weary willingness to humour their younger daughter, my parents put up zero resistance. In December 2020, HereAfter's interviewer, a friendly woman named Meredith, spoke to each of them for several hours. The company then took those responses and started stitching them together to create the voice assistants.

A couple of months later, a note popped into my inbox from Vlahos. My virtual parents were ready.

This Mum and Dad arrived via email attachment. I could communicate with them through the Alexa app on a phone or an Amazon Echo device. I was eager to hear them – but I had to wait several days, because I'd promised *MIT Technology Review*'s podcast team that I'd record my reaction as I spoke to my parents' avatars for the first time.

When I finally opened the file, with my colleagues watching and listening on Zoom, my hands were shaking. London was in a long, cold, depressing lockdown, and I hadn't seen my actual, real parents for six months.

"Alexa, open HereAfter," I directed.

"Would you rather speak with Paul or with Jane?" a voice asked.

After a bit of quick mental deliberation, I opted for my mum.

A voice that was hers, but weirdly stiff and cold, spoke.

"Hello, this is Jane Jee and I'm happy to tell you about my life. How are you today?"

I laughed, nervously.

"I'm well, thanks, Mum. How are you?"

Long pause.

"Good. At my end, I'm doing well."

As Rohit Prasad, Alexa's senior vice president and head scientist, promised: "While AI can't eliminate that pain of loss, it can definitely make the memories last."

"You sound kind of unnatural," I said.

She ignored me and carried on speaking.

"Before we start, here are a few pointers. My listening skills aren't the best, unfortunately, so you have to wait until I've finished talking and ask you a question before you say something back. When it's your turn to speak, please keep your answers fairly short. A few words, a simple sentence – that type of thing," she explained. After a bit more introduction, she concluded: "Okay, let's get started. There's so much to talk about. My childhood, career, and my interests. Which of those sounds best?"

Scripted bits like this sounded stilted and strange, but as we moved on, with my mother recounting memories and speaking in her own words, "she" sounded far more relaxed and natural.

Still, this conversation and the ones that followed were limited – when I tried asking my mum's bot about her favourite jewellery, for instance, I got: "Sorry, I didn't understand that. You can try asking another way, or move onto another topic."

There were also mistakes that were jarring to the point of hilarity. One day, Dad's bot asked me how I was. I replied, "I'm feeling sad today." He responded with a cheery, upbeat "Good!"

The overall experience was undeniably weird. Every time I spoke to their virtual versions, it struck me that I could have been talking to my real parents instead. On one occasion, my husband mistook my testing out the bots for an actual phone call. When he realised it wasn't, he rolled his eyes, tutted, and shook his head, as if I were completely deranged.

Earlier this year, I got a demo of a similar technology from a five-year-old startup called StoryFile, which promises to take things to the next level. Its Life service records responses on video rather than just voice alone.

You can pick from hundreds of questions for the subject. Then you record the person answering the questions; this can be done on any device with a camera and a microphone, including a smartphone, though the higher-quality the recording, the better the outcome. After uploading the files, the company turns them into a digital version of the person you can see and speak to. It can only answer the questions it's been programmed to answer – much like HereAfter, just with video.

StoryFile's CEO, Stephen Smith, demonstrated the technology on a video call, where we were joined by his mother. She died earlier this year, but here she was on the call, sitting in a comfy chair in her living room. For a brief time, I could only see her, shared via Smith's screen. She was soft-spoken, with wispy hair and friendly eyes. She seemed wise.

Smith told me that his mother "attended" her own funeral: "At the end she said, 'I guess that's it

from me... goodbye!' and everyone burst into tears." He told me her digital participation was well received by family and friends. And, arguably most important of all, Smith said he's deeply comforted by the fact that he managed to capture his mother on camera before she passed away.

The video technology itself looked relatively slick and professional – though the result still fell vaguely within the uncanny valley, especially in the facial expressions. At points, much as with my own parents, I had to remind myself she wasn't really there.

Both HereAfter and StoryFile aim to preserve someone's life story rather than allowing you to have a full, new conversation with the bot each time. This is one of the major limitations of many current offerings in grief tech: they're generic. These replicas may sound like someone you love, but they know nothing about you. Anyone can talk to them, and they'll reply in the same tone. And the replies to a given question are the same every time you ask.

"The biggest issue with the [existing] technology is the idea you can generate a single universal person," says Justin Harrison, founder of a soon-to-launch service called You, Only Virtual. "But the way we experience people is unique to us."

You, Only Virtual and a few other startups want to go further, arguing that recounting memories won't capture the fundamental essence of a relationship between two people. Harrison wants to create a personalised bot that's for you alone.

The first incarnation of the service, which is set to launch in early 2023, will allow people to build a bot by uploading someone's text messages, emails, and voice conversations. Ultimately, Harrison hopes, people will feed it data as they go; the company is currently building a communication platform that customers will be able to use to message and talk with loved ones while they're still alive. That way, all the data will be readily available to be turned into a bot once they're not.

That is exactly what Harrison has done with his mother, Melodi, who has stage 4 cancer: "I built it by hand using five years of my messages with her. It took 12 hours to export, and it runs to thousands of pages," he says of his chatbot.

Harrison says the interactions he has with the bot are more meaningful to him than if it were simply regurgitating memories. Bot Melodi uses the phrases his mother uses and replies to him in the way she'd reply – calling him "honey," using the emojis she'd use and the same quirks of spelling.

He won't be able to ask Melodi's avatar questions about her life, but that doesn't bother him. The point, for him, is to capture the way someone communicates. "Just recounting memories has little to do with the essence of a relationship," he says.

And what if that person is, in fact, not dead? There's little to stop people from using grief tech to create virtual versions of living people without their consent – for example, an ex.

Avatars that people feel a deep personal connection with can have staying power. In 2016, entrepreneur Eugenia Kuyda built what is thought to be the first bot of this kind after her friend Roman died, using her text conversations with him. (She later founded a startup called Replika, which creates virtual companions not based on real people.)

She found it a hugely helpful way to process her grief, and she still speaks to Roman's bot today, she says, especially around his birthday and the anniversary of his passing.

But she warns that users need to be careful not to think this technology is re-creating or even preserving people. "I didn't want to bring back his clone, but his memory," she says. The intention was to "create a digital monument where you can interact with that person, not in order to pretend they're alive, but to hear about them, remember how they were, and be inspired by them again."

Some people find that hearing the voices of their loved ones after they've gone helps with the grieving process. It's not uncommon for people to listen to voicemails from someone who has died, for example, says Erin Thompson, a clinical psychologist who specialises in grief. A virtual avatar that you can have more of a conversation with could be a valuable, healthy way to stay connected to someone you loved and lost, she says.

But Thompson and others echo Kuyda's warning: it's possible to put too much weight on the technology. A grieving person needs to remember that these bots can only ever capture a small sliver of someone. They are not sentient, and they will not replace healthy, functional human relationships.

"Your parents are not really there. You're talking to them, but it's not really them," says Erica Stonestreet, an associate professor of philosophy at the College of Saint Benedict & Saint John's University, who studies personhood and identity.

Particularly in the first weeks and months after a loved one dies, people struggle to accept the loss and may find any reminders of the person triggering. "In the acute phase of grief, you can get a strong sense of unreality, not being able to accept they're gone," Thompson says. There's a risk that this sort of intense grief could intersect with, or prompt, mental illness, especially if it's being fuelled and prolonged by reminders of the person who's passed away.

Arguably, this risk might be small today given these technologies' flaws. Even though sometimes I fell for the illusion, it was clear my parent bots were not in fact the real deal. But the risk that people might fall too deeply for the phantom of personhood will surely grow as the technology improves.

And there are still other risks. Any service that allows you to create a digital replica of someone without their participation raises some complex ethical issues regarding consent and privacy. While some might argue that permission is less important with someone no longer alive, can't you also argue that the person who generated the other side of the conversation should have a say too?

And what if that person is not, in fact, dead? There's little to stop people from using grief tech to create virtual versions of living people without their consent – for example, an ex. Companies that sell services powered by past messages are aware of this possibility and say they will delete a person's data if that individual requests it. But companies are not obliged to do any checks to make sure their technology is being limited to people who have consented or died. There's no law to stop anyone from creating avatars of other people, and good luck explaining it to your local police department. Imagine how you'd feel if you learnt there was a virtual version of you out there, somewhere, under somebody else's control.

If digital replicas become mainstream, there will inevitably need to be new processes and norms around the legacies we leave behind online. And if we've learnt anything from the history of technological development, we'll be better off if we grapple with the possibility of these replicas' misuse before, not after, they reach mass adoption.

Will that ever happen, though? You, Only Virtual uses the tagline "Never Have to Say Goodbye" – but it's not clear how many people want or are ready for a world like that. Grieving for those who've passed away is, for most people, one of the few aspects of life still largely untouched by modern technology.

On a more mundane level, the costs could be a drawback. Although some of these services have free versions, they can easily run into the hundreds if not thousands of dollars.

HereAfter's top-tier unlimited version lets you record as many conversations with the subject as you like, and it costs US$8.99 a month. That may sound cheaper than StoryFile's one-off US$499 payment to access its premium, unlimited package of services. However, at US$108 per year, HereAfter services could quickly add up if you do some ghoulish back-of-the-envelope math on lifetime costs. It's a similar situation with You, Only Virtual, which is slated to cost somewhere between US$9.99 and US$19.99 a month when it launches.

Creating an avatar or chatbot of someone also requires time and effort, not least of which is just building up the energy and motivation to get started. This is true both for the user and for the subject, who may be nearing death and whose active participation may be required.

Fundamentally, people don't like grappling with the fact they are going to die, says Marius Ursache, who launched a company called Eternime in 2014. Its idea was to create a sort of Tamagotchi that people could train while they were alive to preserve a digital version of themselves. It received a huge surge of interest from people around the world, but few went on to adopt it. The company shuttered in 2018 after failing to pick up enough users.

"It's something you can put off until next week, next month, next year," he says. "People assume that AI is the key to breaking this. But really, it's human behaviour."

Kuyda agrees: "People are extremely scared of death. They don't want to talk about it or touch it. When you take a stick and start poking, it freaks them out. They'd rather pretend it doesn't exist."

Ursache tried a low-tech approach on his own parents, giving them paper and pens on his birthday and asking them to write down their memories and life stories. His mother wrote two pages, but his father said he'd been too busy. In the end, he asked if he could record some conversations with them, but they never managed to get around to it.

"My dad passed away last year, and I never did those recordings, and now I feel like an idiot," he says.

Personally, I have mixed feelings about my experiment. I'm glad to have these virtual, audio versions of my mum and dad, even if they're imperfect. They've enabled me to learn new things about my parents, and it's comforting to think that those bots will be there even when they aren't. I'm already thinking about who else I might want to capture digitally – my husband (who will probably roll his eyes again), my sister, maybe even my friends.

On the other hand, like a lot of people, I don't want to think about what will happen when the people I love die. It's uncomfortable, and many people reflexively flinch when I mention my morbid project. And I can't help but find it sad that it took a stranger Zoom-interviewing my parents from another continent for me to properly appreciate the multifaceted, complex people they are. But I feel lucky to have had the chance to grasp that – and to still have the precious opportunity to spend more time with them, and learn more about them, face to face, no technology involved.

CHARLOTTE JEE is a based in London. This article was first published in *MIT Technology Review.*

YAGI STUDIO / GETTY IMAGES

Australia is braced for invasion by the glassy winged sharpshooter, but happily much of the science needed to control the damaging leafhopper is already done, writes **Martin J Kernan.**

As Director of Emergency Management in New South Wales, Dr Leigh Pilkington is on the lookout for a mottled brown leafhopper with transparent wings and bulging eyes. There are ivory spots running along its abdomen, and like the fleas that spread bubonic plague throughout the world, in its mouth it carries doom.

People aren't at risk: only plants. Ones that bear grapes, citrus, and olives are particularly susceptible though numerous others have fallen prey. Out of over 600 invasive plant pests threatening the country, the glassy winged sharpshooter, *Homalodisca vitripennis*, ranks in the top 10, poised as it is to destroy Australia's vineyards one grapevine at a time. Of the 175 plant species that sharpshooters are keen to feed on, including eucalypt types, all but one grow in Australia.

"If it arrives with the pathogen *Xylella fastidiosa* then it's going to be a massive problem," Pilkington says.

X. fastidiosa reigns supreme as number one among all biosecurity threats to Australia's agricultural crops. It's a lethal bacterium that lives in the mouths of sharpshooters, infecting and killing the plants they eat. A living sharpshooter hasn't been discovered in Australia yet, though dead ones turn up occasionally in the cargo hold of airplanes landing here. If someone stumbles upon a live insect resembling this highly mobile harbinger of viniculture ruin, it must be reported within 24 hours by calling the Exotic Plant Pest Hotline at 1800 084 881, which triggers a series of defensive measures that play out in rapid succession.

The suspicious bug will be rushed to the premier testing facility in Camden, south of Sydney, for species identification. A male is required for the definitive ID test: the genitalia is macerated, and the soft connective tissue peeled away so its unique genital structures can be compared to anatomical sketches.

Meanwhile, Pilkington's biosecurity team in the NSW Department of Primary Industries will coordinate with the Commonwealth to quarantine the place where the leafhopper was found and conduct intense surveillance of surrounding areas. Technically known as delimiting surveys, this protocol aims to contain the invasive plant pests while attempts are made to eradicate it.

During such emergencies, Pilkington says, "To catch things, you got to be quick, and you got to be decisive, and you don't muck around."

That's because there are great savings for Australia if we stomp out plant, animal, or microbial invaders before they establish themselves, and Pilkington refers to what is called the biosecurity continuum as a visualisation of the adage: an ounce of prevention is worth a pound of cure.

But if the sharpshooter isn't caught before it infests a vineyard, a tree nursery, or any place where irrigation fosters leafy growth, then the only

RIGHT: BRETT DAVIES, PHOTOSIGHTFACES / GETTY IMAGES

It's thought Australia's grape and wine industries are most at risk from the Xylella pathogen carried by glassy winged sharpshooters. A 2014 research article in *California Agriculture* estimated the California grape industry's yearly lost production and vine replacement costs at US$56.1 million.

proven way to stop its spread is through biological pest control.

Pilkington learned the science of using bugs to fight bugs from Dr Mark Hoddle, the leading practitioner in the field. From 2004 to 2005, as a postdoctoral fellow at the University of California Riverside (UC Riverside), Pilkington studied the sharpshooter's life cycle in Hoddle's lab, examining the tight rows of oblong eggs they inject into the underside of leaves. He calculated the 10 to 14 days it took the eggs to hatch inside temperature-controlled cabinets, then watched them mature and begin using their piercing-sucking mouthparts to extract and nourish themselves with the viscous fluid called xylem that keeps plants hydrated.

If the plant's plumbing becomes corroded with *X. fastidiosa* bacteria, it will stop absorbing enough water to survive. Symptoms of Xylella manifest in a dry burnt appearance, aptly called leaf scorch, which precedes the plant's inevitable demise. There is no treatment or cure for the disease. And as the plant dies of thirst it becomes a reservoir of the bacteria – a poison well from which other sharpshooters, immune to the toxic effects, blithely drink so that they become carriers, if they aren't already, and unwittingly transport Xylella to other plant hosts.

Pierce's disease – caused by Xylella bacteria – typically inflicts a dry, burnt appearance (above) known as leaf scorch. Researchers (below) Julie Grandgirard, Christina Hoddle and (opposite top) Mark Hoddle raised parasitical ashmeadi wasps to counter the Xylella-bearing glassy winged sharpshooters in Tahiti (opposite). There, sharpshooters were almost entirely eliminated.

Sour grape growers in California

A wide variety of vegetation in California succumbed to Xylella in the late 1990s and early 2000s, delivered by sharpshooters that snuck in as eggs on plants imported from the southeastern US. By the late 1990s, Xylella had decimated $US52 million worth of oleanders planted to beautify 3200 kilometres of California highway. It also struck at the heart of California agriculture: its grape and wine industries, wiping out nearly $US40 million of production in San Diego and Riverside counties in a single growing season. Estimates put total damage to California in the astronomical $US33 billion range. Similar losses are projected for Australia, should the sharpshooter move in undetected and multiply exponentially as it did in the US.

When agricultural interests or ecologies face existential invasive threats like Xylella, governments turn to Hoddle, a ruddy Kiwi transplanted to California who pioneered some of the most effective biological control programs in history.

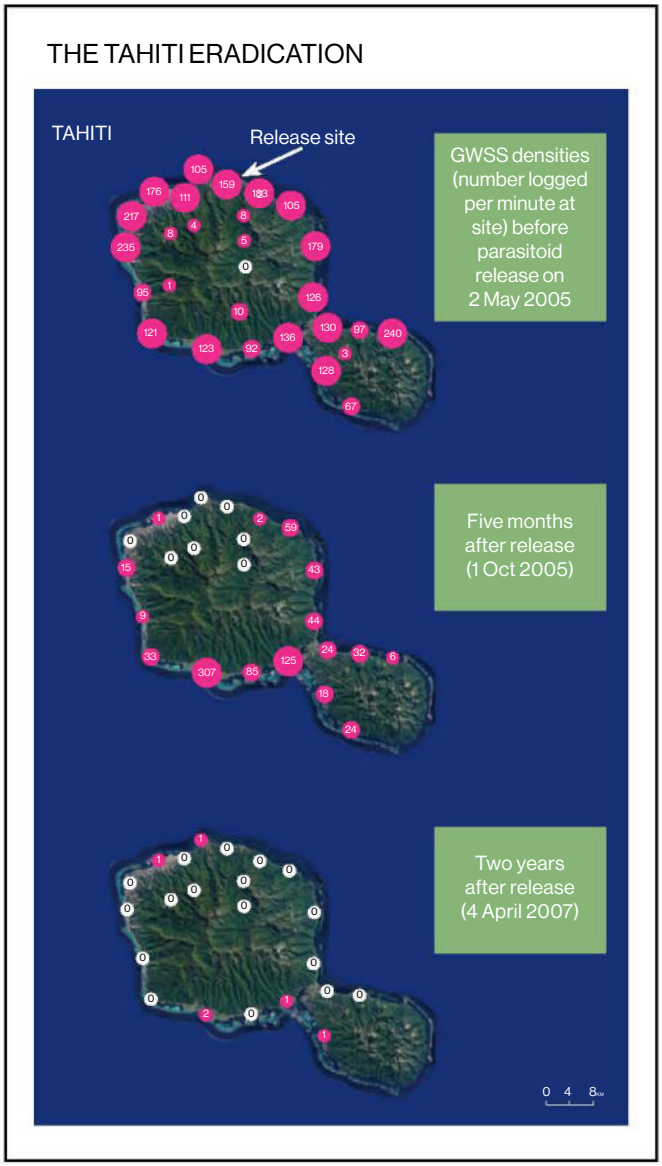
In the early 2000s, he saved mangrove forests in the Galápagos Islands from an invasion of cottony cushion scales. These scales appear as fuzzy white scabs of infestation on fruit trees and like sharpshooters use a straw-like proboscis to extract fluids. In doing so they avoid pesticides sprayed on the surface. To rescue the Galápagos' precious ecologies, Hoddle reenacted the most successful application of biocontrol ever recorded. In 1888, Albert Koebele, an entomologist working for the US Department of Agriculture, took a steamer to Australia at the behest of his superior, the eminent scientist Charles Valentine Riley, in search of the cottony cushion scale's natural enemy. There he discovered its co-evolved predator, a tiny species of ladybug: *Novius cardinalis*. Released upon Los Angeles' dying citrus groves, these ladybugs, also known as vedalia beetles, stunned everyone by ravenously devouring all the scale on thousands of acres of orange and lemon trees within weeks.

In the Galápagos, the Novius ladybugs imported from Brisbane, Australia and deployed by Hoddle performed similarly. He had to try do the same for California's grape growers. But how does one find such spectacularly helpful bugs?

"Fortunately, for me, here at the UC Riverside we have one of the world's premier experts in the

LEFT: MARK HODDLE / UC RIVERSIDE. ABOVE: MAZZO1982 / GETTY IMAGES

In the southeastern US where the glassy winged sharpshooter evolved, researchers found its co-evolved parasite: a stingless wasp little bigger than a fleck of dust.



FROM TOP: MARK HODDLE / UC RIVERSIDE; GOOGLE EARTH

parasitoids of leafhoppers," Hoddle says. "He's a taxonomist. His name Serguei Triapitsyn."

In the southeastern US where the glassy winged sharpshooter evolved, Hoddle and Triapitsyn found its co-evolved parasite: *Gonatocerus ashmeadi*. It's a stingless fairy wasp, or fairyfly, little bigger than a fleck of dust. The wasp and much larger sharpshooter (about 12mm long) don't confront each other face to face. As a parasitoid, the female wasp uses the sharpshooter's egg as sustenance for its own brood by chewing a hole through the egg casing and laying its own inside. The wasp larvae then devour the sharpshooter's eggs from the inside out.

Hedging his bets, Hoddle sent Pilkington to Mexico to find other parasitoid candidates for this biocontrol job. They put several, including the ashmeadi wasp, through rigorous testing aimed mostly at ensuring the bugs only targeted sharpshooters' eggs, so as not to impact innocent native leafhoppers that don't carry Xylella. In trials, ashmeadi wasps parasitised an impressive 76% of the sharpshooters' eggs, aided by chemical signals the plants emit as a sort of distress call. None of the other parasites could compete with the wasp's unique ability to home in on these plant signals.

But there was no telling if the ashmeadi wasp would behave the same as it did in its native range. Anything can happen in California. You could be eaten by predators, find more attractive leafhopper eggs to parasitise, or simply fly off and disappear never to be heard from again. Luckily none of these scenarios came to fruition and by 2005, sharpshooters nearly passed out of existence in California. But not quite; they're a fit, hardy, and adaptable insect, albeit now kept at less menacing levels by a natural parasitoid.

At the height of the sharpshooter crisis in California, Hoddle invited Pilkington and other scientists from Oceania to assess the invasion risk for their own countries. In small re-creations of New Zealand and Australian ecologies on the UC Riverside campus, researchers tested whether sharpshooters attacked and laid eggs on the antipodean native plants, and whether the wasp

would then parasitise those eggs. The answer after two and a half years of close observation: an unqualified yes.

Don't bungle the jungle in French Polynesia

In 2001, French Polynesian entomologist Rudy Gérald was jogging up a mountain trail in Pirae, Tahiti, and even though there wasn't a cloud in the sky, rain poured on him through heavy foliage. Closer inspection revealed glassy winged sharpshooters had infested the entire area. They were everywhere, even at the rim of a volcano at 440 metres elevation. The rain Gérald felt was actually sharpshooter pee; soon the bug was making headlines as the "pissing fly" in island newspapers. Its liquid excrement collected in puddles in parks, fell on windshields, and showered families strolling down tree lined streets.

The dense Polynesian forests served up an endless supply of xylem, which isn't very nutritious and must be consumed in such large quantities that it passes through sharpshooters in a stream. The warm wet climate, meanwhile, let sharpshooters breed all year round and propagate into biblical hordes. Overwintering was no longer necessary. And to make matters infinitely worse, no fauna in French Polynesia seemed interested in eating sharpshooters. Spiders tried but died in convulsions because sharpshooters proved to be toxic. Sharpshooters flew indoors and probed peoples' pores for xylem with their needle-like mouths. They swarmed outdoor lighting and blackened the night. They became a public nuisance on a grand scale.

In 2004 an email popped into Hoddle's inbox from an agricultural official in French Polynesia who was in dire need of help. The official said he had glassy winged sharpshooters there, and that they were really bad. Hoddle replied from California saying, yeah, we've got them here too, and they're really bad. The official said, no, I mean, they're really bad here. Hoddle said they can't be any worse than what he had in California. Well, you need to come down and have a look, the official said.

"So, then I was intrigued, and I went down and had a look, and I was like, 'oh my God'," Hoddle says.

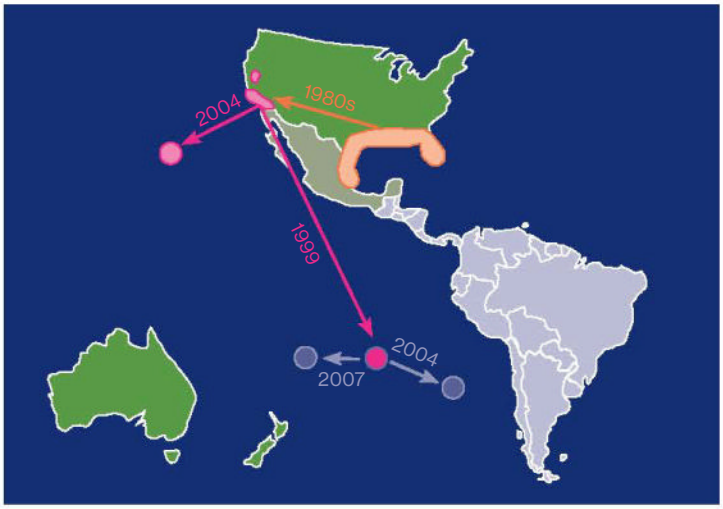
French Polynesian agricultural officials became justifiably anxious about the unintended consequences of releasing a parasitic wasp into the complex ecology of their lush tropical forests. How can you be sure, they queried Hoddle, that it won't destroy native flora and fauna?

Over the next 18 months Hoddle showed them. Setting out from the University of California Berkeley's Gump Station on the island of Moorea, researchers Julie Grandgirard and Jérôme Petit scoured the countryside for the eggs of all the known native leafhoppers. Then in a tightly controlled environment they exposed the eggs to ashmeadi wasps.

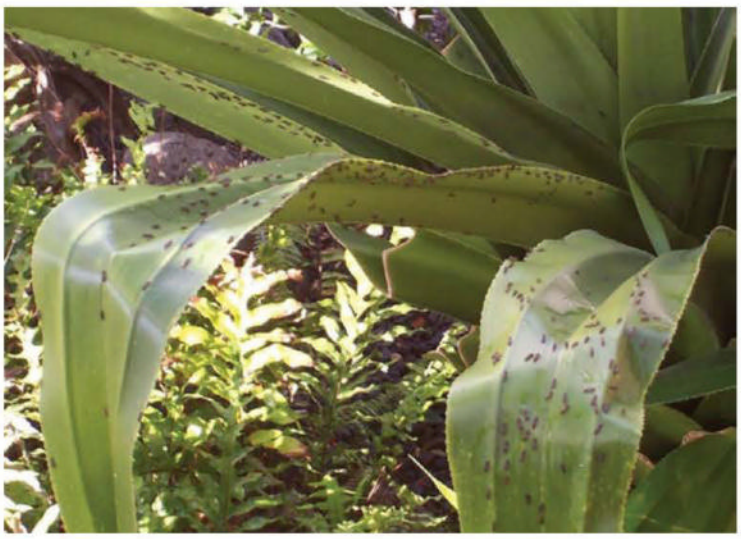
"Even to this day," Hoddle says, "we have no evidence of our parasite attacking anything else in French Polynesia other than the glassy winged sharpshooter."

Next step: rear enough ashmeadi wasps for a mass release operation across Tahiti and Moorea. In 2005 Hoddle and his wife Christina, who is also

Sharpshooter's odyssey



Endemic to the southeastern US and eastern Mexico, the glassy winged sharpshooter found its way to California in the late 1980s, where it spread Pierce's disease through, and wreaked havoc in, horticultural industries in the 1990s. From California the sharpshooter spread to French Polynesia (1999) and Hawaii (2004), and from French Polynesia to Easter Island (2004) and the Cook Islands (2007). "Wherever this insect went," says researcher Mark Hoddle, "the numbers of this insect blew up into densities of biblical proportion."



The sharpshooter was first detected in French Polynesia in 2001; by 2005 its abundance (below) had reached public-nuisance scale. Researchers didn't have to rear them: there were abundant eggs on leaves near labs.

MARK HODDLE / UC RIVERSIDE

MIKE LEWIS / UC RIVERSIDE

an entomologist, arrived in Moorea with big boxes of wasps in tow and emerged from customs into a throng of media.

"When we walked out there were television cameras everywhere, reporters with big microphones, and we were just shocked," he says. "The word had gone around that we were here to save the islands from this insect."

Reporters tailed them in paparazzi fashion to the Gump Station where they, along with Grandgirard and Petit, began rearing ashmeadi wasps.

"There were so many sharpshooters outside the quarantine facility we could just run outside and grab 100 leaves full of eggs," Hoddle says. "We didn't have to maintain cages of glassy winged sharpshooter colonies to rear the parasite, there were just so many eggs outside."

On 2 May 2005, with television cameras rolling, they released the first of 14,000 wasps and then every few weeks trekked to remote locations scattered throughout the islands of Moorea and Tahiti to survey sharpshooter densities.

"Glassy winged sharpshooters love hibiscus bushes, and we would count the numbers of eggs, nymphs and adult sharpshooters on those bushes," Hoddle explains.

"And we would measure what percentage the parasitism levels were. We started off with just insanely high numbers of sharpshooters on these hibiscus bushes. And then very rapidly over a seven-month period, they fizzled out to almost nothing."

The sharpshooters that had spread to all the Society Islands by 2005 had virtually disappeared by 2007. Those present in Easter Island, the Cook Islands and Hawaii persist today only at very low numbers. Hoddle thinks that the progeny of his wasps tagged along inside the eggs of sharpshooters and stymied reproduction efforts there as well.

"We started off with just insanely high numbers of sharpshooters on these hibiscus bushes. And then very rapidly... they fizzled out to almost nothing."

On the heels of this success, Hoddle and Pilkington tried and failed to convince the Australian Government to approve, prophylactically, a program to release ashmeadi wasps if someday the testing lab in Camden confirms the presence of glassy winged sharpshooters in Australia. Pilkington believes there will be time to get that approval before extensive damage is done and sees biocontrol as a long-term mitigation tool. Pesticides are the first line of defence, he says.

Now, Hoddle says, there's no need for Australia to spend hundreds of thousands or maybe millions of dollars doing all the safety testing again.

"We did all those experiments," he says, "and the answers were pretty clear. Yes, glassy winged sharpshooters will feed on native Australian plants. Yes, glassy winged sharpshooters will lay eggs on native Australian plants. Yes, the parasite will chase those eggs on native Australian plants and parasitise them too. A lot of the basic, fundamental work is done."

At about 12mm in length, the glassy winged sharpshooter (GWSS; above left) is the heavyweight in its biological bout with the delicate, 1–2mm long ashmeadi wasp (above right) – but in this case, size really doesn't matter. The female wasp lays its eggs in GWSS eggs; its larvae gorge on the GWSS egg, destroying it, then pupate inside the egg casing before emerging through a tiny circular opening.

MARTIN J KERNAN is a freelance science writer based in New York. This is his first story for the magazine.

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ZEIT

Argentinian artist Tomás Saraceno's explorations of air and its meaning have graced museums and galleries around the world: *A Thermodynamic Imaginary* is shown here. "We can now think to move together towards an aerosolar ethos, embodying an ever more tangled relationship with the atmosphere, the air and the cosmos," wrote Portugal's Museum of Art, Architecture and Technology upon exhibiting Saraceno in 2018. "This would take a thermodynamic leap of imagination... We could call this the Aerocene." For more on Saraceno, turn to page 102.

MONA/JESSE HUNNIFORD

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A DAY IN THE (MOON) LIFE

The Artemis program is up and running, and humans could be back on the Moon's surface in 2025. What will life be like for the next generation of lunar explorers? **Jamie Seidel** gazes into the crystal ball...

Day 42: 05:55

The day starts just like any other. You wake up. Things get a bit out of this world from there. Even lying on the bunk with closed eyes, things don't feel right.

The sounds. It's not that there aren't any. It's just that there are so few of them that each one rings out crisp and clear, no matter how soft they are.

They've got no background noise to compete with.

Oh, the fans are droning on as they always do. No expense had been spared in the drive to keep them quiet. And it had worked. Apparently. For a time, at least. Now, each individual tick, grind and squeak has an almost physical presence.

The scrubbers are guaranteed to filter out 99.9% of all the hair and grime deposited in any human environment. Not to mention dust.

Dust. Don't mention the dust.

That 0.1% adds up quickly, your predecessor had warned. She'd "strongly recommended" you include a stash of soothing salve among your precious 1.5 kilograms of personal luggage.

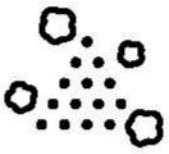
The trouble is, this isn't just any dust.

Dust you can handle. Dust you know. You'd lived with the burnt-red beast in your underwear for months during training at the Arkaroola habitat simulator, in South Australia.

But this is regolith. Every grain is tiny. Every grain is sharp. Every grain is electrostatically charged. In practical terms, it's a 0.07 millimetre piece of shattered glass that sticks to anything and turns it into industrial-grade sandpaper.

Not for the first time, you wish all the wind expelled at those lectures about the "regolith problem" had been canned and shipped to the Moon to erode the stuff.

Dust 1, Boffins 0.

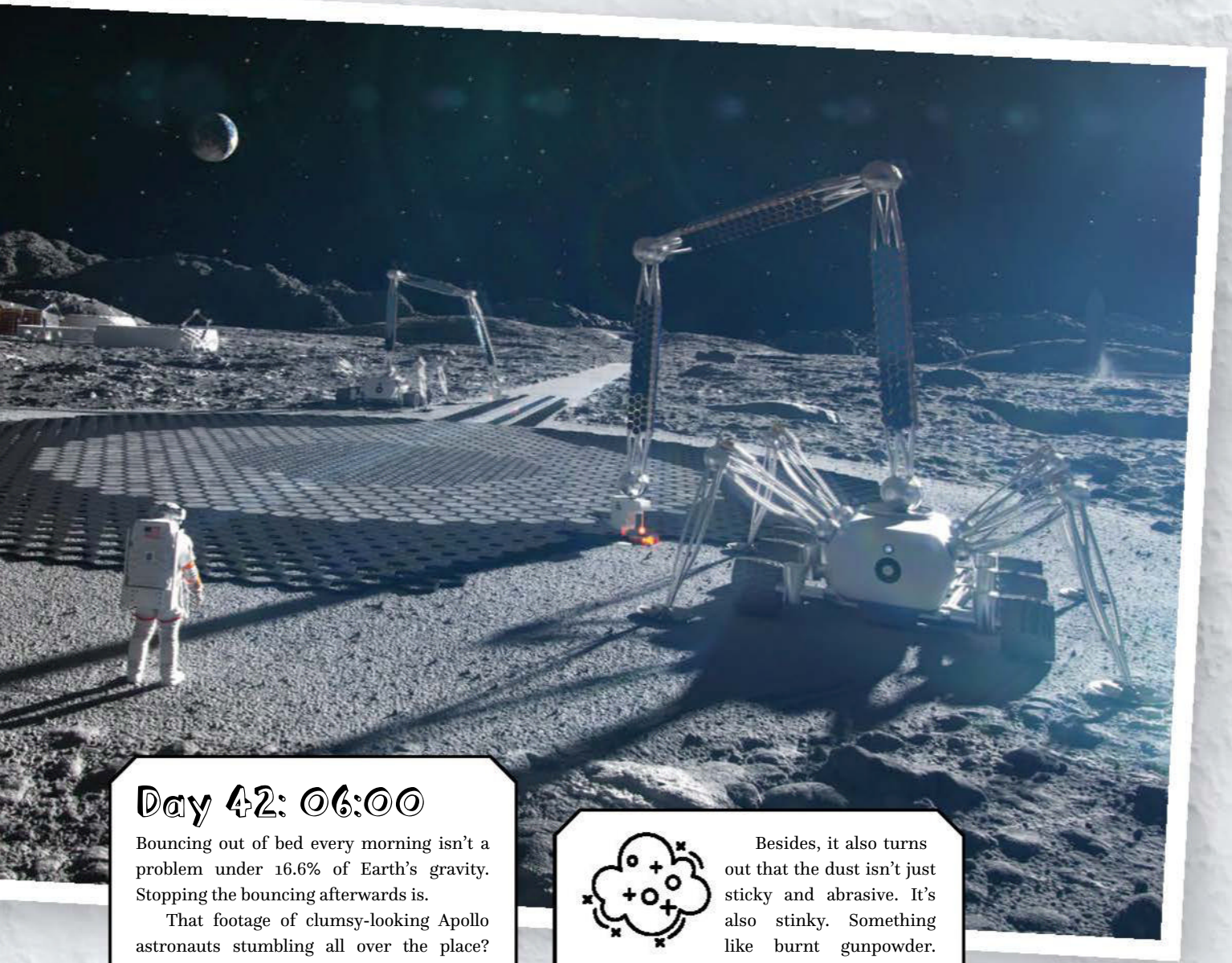


The lights come on. Dim, to save electricity. Time to get up – preferably without bashing your head on the roof again this time.

A crash. A curse. You hear your companion laugh. You sigh.

Ten square metres per astronaut, NASA's Lunar Cabin specifications had read. Not enough had been allocated to headroom.

ALL ICONS: THE NOUN PROJECT



Day 42: 06:00

Bouncing out of bed every morning isn't a problem under 16.6% of Earth's gravity. Stopping the bouncing afterwards is.

That footage of clumsy-looking Apollo astronauts stumbling all over the place? Halfway through your two-month tour of duty at Base Camp One, it's now just part of everyday life. Even in a form-fitting jumpsuit it looks like something H.R. Giger's Alien would cough up as a furball.

It's a nightmare web of crisscrossing bands, ribs, straps and springs designed to subject your limbs and muscles to directional stresses.

Essentially, it's a gravity substitute. It's supposed to resist the onset of all those horrible bone, muscle and coordination conditions that were such a feature of life for astronauts on the International Space Station.

It. Feels. Weird.

No matter how many elastic bands they've packed into the thing, it simply can't hope to satisfy all the subtle nuances burnt into your brain by 3.7 billion years of evolution.

Besides, it also turns out that the dust isn't just sticky and abrasive. It's also stinky. Something like burnt gunpowder. Remember cap guns?

There are two bunks in the crate-filled cabin. A separate cabin houses the remaining two mission personnel. Between the two is a slightly larger dome for communal living and workspace. It has two airlocks – one leading to the garage, the other to a plant and equipment room.

No expense had been spared in setting up this off-world retreat. Except for aesthetics.

The walls are rigid foam-plastic shells. They'd been hauled here on the first Artemis missions before being inflated, hardened, reinforced – and buried.

Yep, dust again.

It turns out a metre of the stuff is all it takes to block out all but the most harmful solar and intergalactic rays. It may itch, but this property alone has saved tens of billions of dollars being spent on hauling heavy shielding up the steep climb from Earth.

A concept image of a "brickie" robot-rover laying a dust-suppressing landing pad at the lunar south pole.

BACKGROUND: HELEN_F / ADOBE STOCK. ABOVE: NASA

The first Artemis astronauts on the Moon (right) won't be former test pilots; they'll be more like 'tradies' working to build a new community. And forget glittering crystal domes: humanity's first space outpost (below) will be more like a mud hut.

Day 42: 06:15

Bacon and eggs. Breakfast of the gods!

Aaaand a cup of coffee! Real coffee; in a real cup. Including the bitter brew on the shopping list had been a unanimous vote. And an expensive one.

The average coffee drinker consumes about 4kg of ground beans annually. For a two-month tour of duty on the Moon, that equals 666 grams each. Or 2.7kg (rounded up!) for the entire four-person team.

At a going rate of about $1.5 million per kilogram for delivery...

Hey, you're a brickie! Not a mathematician. Working out the cost of a lunar cuppa is outside your pay grade. Whatever it is, it's the price of good morale, and you're glad for a regular dose of home.

The eggs are also from Earth. Powdered, of course. But the bacon is indigenous. The "Moonpig" happens to be a remarkably adaptable pond weed floating in trays in the... plant room. Feed it some herbs and spices. Trigger a few gene sequences. Dry it. Toast it.

It's not bacon. But it'll do.

Almost every astronaut ever has lost weight – no matter what they've been force-fed. It's just one of the many poorly understood side effects of low gravity on the human body.

FROM TOP: NASA, ESA

Day 42: 07:00

It costs about $1 billion to ship you 384,400km to the Moon (weight after farewell lunch = top secret!). It's a long way to go for a desk job.

Yep. A desk. A folding chair. A headset. Several screens. A keyboard. Some game controllers. And an enormous whiteboard (cheaper to carry than a big screen).

It's a lot like your first job at an outback mine site really. The heat and dust kept you indoors then. What's a little extra cosmic background radiation – and an absence of atmosphere – anyway?

It's a balmy 0°C outside. It's forecast to stay the same for the rest of the day. Which means pretty much eternity.

Lunar Cabin (seriously, why not Moonbase One?) sits within the southern polar circle. That means perpetual sunlight strikes the ground at a highly oblique angle. So no blistering 120°C days and -130°C nights (which last 656 Earth hours, just saying) as elsewhere on the Moon.

That's also why you're here.

Well, the shadows are. They conceal ice. Mostly water. But there are a few other volatiles mixed in. It hasn't been boiled off into space. That means it can be mined and refined.

Add a little electricity, and you get oxygen and hydrogen. One to breathe. One to burn.

But that's not your job. Not today, at least. You're a brickie. You build things. And battle dust.

Your skillset includes words such as "habitat", "sustainable human presence", "launch pad", "roads", and ... "regolith suppression". Which means doing whatever it takes to beat the stuff into submission.

But the best part is the robots do (almost) all the dirty work. You're the "human in the loop".

Seriously, how hard can laying a bit of pavement be?

Remember Wall-E?

A.R.N.I.E. is a mobile kiln. He has an army of little helper bots scooping and sifting the regolith before feeding it into his onboard oven. He squeezes. And makes a deposit on the ground. Another helper bot waits for it to cool before wiggling it into position and welding it into place.

Day 42: 11:17

Mission Control is complaining that the Road-E Bots are milling about aimlessly. These guys have a tough life out in the elements. Some dig. Some scrape. Some compact. Then along come those that sear.

Yep, they turn regolith into pavement by melting it – the official term is "sintering". And all it takes is for a few millimetres of dust to be glassed, and you get yourself a shiny new road.

Why so much effort? Why burn through so much precious reactor energy? Why spend the big bucks on sending a brickie out alongside the glory gals (and guys) in farming, mining, and habitat?

Well, rover wheels kick up a lot of dust. And once kicked up, it stays up for a disturbingly long time. So paved paths are the simplest way to reduce the daily grind (literally) on just about every surface and piece of equipment on and in the base.

You sigh. If you're not clear enough with your instructions, unexpected things can happen.

There – in the utterly black shadow of a Truck-E Bot: an electrical extension cord snared on a jagged boulder. A Laser-E Bot had mindlessly kept pulling until the plug separated.

And that upset the whole work routine.

Rovers generally need minimal supervision once given a pre-defined task. The trick is feeding them the right amount of detail. Too little, and they make stupid mistakes. Too much, and they risk being micromanaged into a standstill.

You switch a nearby WaldoBot to manual. Then, using your game controllers, you wiggle it around to pick up both halves of the cord, blast the contacts free of dust – and slot them back together.

You glance at the panel in the corner of your screen where the ever-present Earthside technical consultant resides.

"Mission Control, time to talk about a raise."

But the 2.7-second delay for the responding smirk to return kind of kills the moment.

This artist's impression of off-Earth habitation illustrates the importance of the sustainable use of local materials to support the NASA Artemis Program, which is a focus of research at the University of Adelaide's Andy Thomas Centre for Space Resources.

Day 42: 14:22

It's time for an E.C.A. (Extra Cabinular Activity). Or, in English, to go outside.

A.R.N.I.E. is screaming for help. Again. He's really just a big baby. A Volkswagen-sized baby. But his job is vital: he's building the landing pad.

Rocket plume + super-sticky dust = sandblasting.

Every time we get a new delivery or change in work rotation, hundreds of thousands of kilograms of Moon stuff gets blasted across the surface. Some regolith even gets propelled into orbit.

All those hyperenergetic particles could soon pose a severe problem for the Lunar Gateway space station, all those communications satellites – and your ride home...

A.R.N.I.E. is getting too hot. And his onboard sensors don't know why. That's why you're here. Kick the tyres. Tighten the bolts. Bash the casing to shake all the dust loose.

Doing that involves going outside. Seeing your footprint on the Moon's surface the first time was a moment beyond compare. An even-dozen Moonwalks later – not so much.

Going outside is a serious P.I.T.A. First, you have to get out of your G-suit. Under Moon gravity, that's some serious gymnastics right there! Then it's time to put on the super absorbent underwear. Not exactly a nappy... And there's the "urine collection device" (™) attached.

Don't forget the cooling suit. It's not that the sunshine's a problem. It's just that, without atmosphere, there's nowhere for all your body heat to go.

Then there's the webbing holding all the biosensors and other gubbins that make sure everybody knows EXACTLY everything your body is doing...

Only then do you get to enter the airlock. It's not one of those double-doored things you see on all the sci-fi shows. Yes, a pressure door seals off the cabin. But the other door is your suit. It's a suitlock.

Its backpack forms an airtight seal with the cabin itself. A hatch in that backpack is how you climb (well, wiggle) into the pressurised, hardened shell. It looks more like an armoured deep-sea diving suit than anything the Apollo astronauts wore.

It's all about limiting the amount of dust that gets inside. But it's also supposed to protect you from radiation, extreme temperatures, micrometeoroids – and regolith.

Judging from all the scuffs on its surface and the way you struggle to get the seals to close, the dust is winning.

Apollo's astronauts had it easy. Their stuff only had to last 22 hours.

NASA X2

Day 42: 15:32

Panic attack! Breathe deep. It passes in a few moments. Nothing like practice...

The lunar landscape before you looks like a bad V.R. scene. The lighting's all wrong. The edges are way too clearly defined. And not only is the colour on the blink, but the black-and-white mode has dropped white for 50 more shades of grey. But one sight makes it all worthwhile.

You turn to face the Earth.

It hasn't gone anywhere. The Moon's tidal locked. That means the Earth always sees the same face of the Moon. From the Moon, it means the Earth never moves.

It's bright. It's blue and white. It's upside down. That's fine: There's Australia in its rightful place – on top of the world.

The rest of the sky is pitch black. There's no atmosphere to scatter the sunlight. That's also why every shadow is totally dark. And why every edge – be it artificial or not – appears so stark.

The stars, though, are crystal clear. And hypnotising.

Don't look up!

You do your best Neil Armstrong impression as you make your way around the cabin to the improvised vehicle park. They should be in the garage, but priorities change. Other, more important things need to be shielded from the environment.

The last functional golf buggy is parked next to the heart and soul of the lunar cabin: a 3D printer. Actually, several different types of printer, all bundled into the same transportable unit. It's alongside the van-sized nuclear reactor.

Which makes sense. Do you have any idea how many ergs go into making a plastic fork? Think a lot, then scale that up to mixing and matching the materials needed for something like a robotic arm.

It's also why the lights are dim inside.

The rovers, robots and vehicles need more parts replaced more frequently than anticipated (#dustindrivetrains). A bit like home, really.

Day 42: 15:44

While you call yourself a brickie, you know A.R.N.I.E. and his fellow tradies do all the work.

Rovers come in all shapes and sizes. There are a few monsters. But, mostly, they are Tonka trucks that (try) to do all the odd jobs you'd normally expect a human to do back home.

Except think.

Your fleshy fingers program the size, number and pattern of geometric bricks A.R.N.I.E... excretes. The bots then slot the interlocking blocks (which look disturbingly like bone sockets) in place.

Until they don't. And that's where you come in.

It seems the definition of human has narrowed to the ability to make workable inferences based on sparse data.

God of the gaps! Oorah!

A.R.N.I.E.'s dirty. We're talking Victorian-era-coalminer dirty. Every exposed surface is smeared and grimy. All those gizmos and gadgets incorporated into the design to prevent dust problems have been overwhelmed.

And that's your cue, Sherlock.

You unlatch a few pieces of fairing and remove some insulation. It all takes far too long. They still haven't invented practical pressurised gloves.

But, at last, it's out with the magnifying glass.

Yep, you knew it. Dust. Where there's a seam, dust will find a way. A flush-fitting radiator and actuator motor housing have worked apart just enough to allow in a few 0.07mm grains. From there, it was all downhill. Eventually, enough had forced its way in to separate the two parts entirely.

Heat with nowhere to go equals too much heat.

The fix? Pull it apart. Very slowly so as not to stir up more dust. An intense blast with your pencil-sized air jet. A quick wipe with a microfibre rag... and contact is made.

The solution? Obvious! Cover the actuator with a plastic bag. And duct tape (it still holds the universe together). This time, though, you're thankful you didn't have to resort to fencing wire. You're running low.

"Still waiting for that raise," you quip to those voices in your head.

NASA X2

Robots won't be enough on the Moon: human problem-solving and ingenuity will be central to the Lunar Cabin's success.

Day 42: 17:07

It's been a long afternoon. And you forgot to pack a snack. You wince. There's certain to be an OHS form to fill out about that one once you get back inside.

But that'll have to wait. There's a problem. And since you're already outside, you've been volunteered!

Your buggy labours its way up a lunar mound. Deep ruts mar the once-pristine moonscape and make for a rough, dirty ride. The Road-E bots still have a long way to go.

You crest the ridge to a dazzling sight. It's an enormous glowing dust cloud. With occasional sparkles.

Plasma discharge. Yep, moon lightning.

All made possible by the annoying way the Sun gives the dust it shines upon a positive glow. But the regolith in the ultra-dark permanent shadows has a somewhat more negative attitude.

Close the circuit between light and dark with a few stirred-up particles, and the result is shocking. Literally. You can imagine what that does to the sensitive miniaturised sensors and communications equipment on any nearby autonomous rover.

Mostly, they get amnesia. They forget where they are. And sometimes they're not able to make sense of all the strategic landmarks put in place for that exact reason.

Have you tried turning it off and on?

That's your job.

A Boss-E bot is the latest victim. It's a mobile sensor and communications platform designed to double-check the quality of construction work.

Under the glowing cloud is the future Moon Base One. At the moment it's just a hole in the ground (a partially graded and compacted field). And the rovers are busily building their own bomb shelters before tackling anything serious.

They're slotting pre-shaped bricks into tilted arches. It's an idea ripped straight out of ancient Mesopotamia – gravity helps hold everything in place. And the arches can be extended into tubular enclosures.

Usually, you get about two to three days' notice of an impending solar storm.

But it could be less than 12 hours.

So you need something to protect any static equipment. And somewhere for the rovers to scurry for shelter.

This Boss-E bot was supposed to be double-checking the fit of the bricks. One unwanted gap could potentially let in enough rays to fry an unsuspecting machine. Or person.

There it is: with derelict Brick-E bot alongside it.

You jump off the golf buggy a little too quickly. The resulting faceplant isn't at all embarrassing. But the alienesque dust angel you left behind is well worth the memory.

Your suit is caked with regolith. But you mentally brush it aside.

What's a little more dust anyway?

Less play! More work! That promotion is at stake!

You detach a screwdriver-thing from your belt and lean over the rovers.

"You got a lot of carbon scoring. Looks like you boys have seen a lot of action," you breathe into your mic. Would those cardboard-cutout mission control types even get the Star Wars R2D2 reference, you wonder?

You lean forward. A spark leaps from the lifeless Boss-E bot towards your regolith-caked glove. Then another. And another.

You smell smoke. In a spacesuit.

"Houston, we have a problem ..."

JAMIE SEIDEL is a freelance journalist based in Adelaide. His most recent story for Cosmos appeared in Issue 97.

The Oceans of Air exhibition at MONA, Tasmania, features Saraceno's globular creations Aerocene 2.5, 4 and 5. "Once upon a time artists used to make beautiful things," says David Walsh, MONA's founder and owner. "Now, mostly, they want to change the world. Of the artists I know, Tomás Saraceno is the most likely to change the world. And he makes beautiful things."

THE ART OF AIR

Can creativity help us understand the complexity of the tiny bubble we inhabit? **Ashley Hay** talks to artist Tomás Saraceno about visualising our atmosphere, spiders' cosmic connections, the art of science – and the science of art.

Hanging at the heart of Tomás Saraceno's "Oceans of Air" exhibition in Hobart's Museum of Old and New Art (MONA) are eight large glass vivaria, suspended and spotlit in one room's darkened space. Their individual pools of golden light reveal collaborative networks of spiders' webs in each – one created by a solo *Nephila senegalensis*, an ensemble of *Cyrtophora citricola* and two *Araneus diadematus*; another by a combination of two *N. senegalensis*, one *Eratigena atrica*, one *Parasteatoda tepidariorium* and a single *Uloborus walckenaerius*. Spiders and webs – or spider/webs, as Saraceno calls them, to underline the unity of creature and creation involved here – are central not only to the Argentinian artist's work, but also to his worldview, both artistic and scientific. In *Oceans of Air*, these silken sculptures are presented as just some of the work the museum's visitors can gaze at, think into, and admire. But this artistic evocation sits alongside Saraceno's involvement as a contributing author for the 2021 *PNAS* paper – "In situ three-dimensional spider web construction and mechanics" – as part of a research team led by the Laboratory for Atomic and Molecular Mechanics at MIT.

Science and art; art and science. Saraceno is less interested in divisions between these two spaces. For him, "with the world in crisis as it is, science is as much the cause – the problem – as it is also the possibility of the solution." What he hopes is that science can be rearticulated through "a great tradition called 'TEK' – traditional ecological knowledge – which might imply other forms of knowledge that have been neglected, rejected, refused as indigenous knowledge."

These phrases underpin Saraceno's body of work – the projects he's been involved with for more than two decades around the world, and which are in Australia both at MONA, and in a new work, "Drift: A cosmic web of thermodynamic rhythms", commissioned by the QAGOMA show *Air*, in Brisbane.

In "Drift", 15 spheres, half mirrored and half transparent, ranging from 1.2m to 6m in diameter, fill QAGOMA's central atrium. Some float; some rise and fall, slowly, gently, as if they were linked to the tides on this, Earth's larger sphere. They create a vast and reflective space.

But are they mighty magnifications of life at an atomic level – or are they designed to reduce the people who move between them to a more micronic scale? Are they a diminutive array of planets from the cosmos? For Saraceno, any question of scale is "always complicated". To his mind, thinking about air, its life-giving, its ubiquity, means also acknowledging that "we live in this planetary boundary where ...maintaining certain forms of life [means

MONA/JESSE HUNNIFORD

living] within the threshold of 1.5 degrees. So [Drift's] sculptures are almost barometers – they allow you to sense the increase of global temperature that might forecast some different forms of life emerging while others are being destroyed."

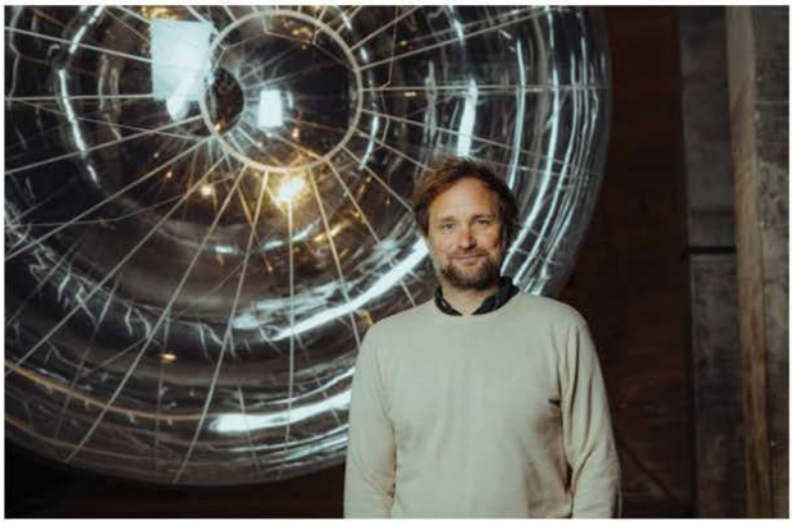
"When we think of 'float', we think of water, not so much air, but it's exactly the same."

It was one of the work's intentions, he adds, that these spheres were "really able to float on rivers of air". "Torricelli, a student of Galileo, said we live at the bottom of rivers of air, but somehow, through the evolution of life, not many have been granted the ability to float in the air." Think of Archimedes, he says. "When we think of 'float', we think of water, not so much air, but it's exactly the same."

Saraceno is enthusiastic about exchanging ideas across the notional – and relatively recent – fenceline between art and science: what gives him hope is the possibility of building bridges between the two. "When I think about how our mobility could be crafted around synergy with the elements," he says; "if we learn how to move with these winds, it might allow us to live on the planet in a completely different way."

The same potential is evident in the idea of researching not just spiders, but also their webs. As the 2021 *PNAS* paper explains, such work could reveal "an innovative assembly method for stable, functional, repairable, and reinforceable fibre structures".

"Expanding our knowledge of spiders' web construction, silk recycling, web monitoring, and repair methods could inspire novel self-sufficient, self-repairable, and self-monitored smart structures," the authors note.



Saraceno has been thinking about spider/webs since he was a child, as well as thinking about air – how it moves and what's in it, on this planet and beyond. His particular passion is for solar-powered balloons and the idea of Earth as a battery that could be used to power them. This aligns with his rejection of this era's insistence (he calls it the Capitalocene) on haste, violence and fossil fuels.

Think of a rocket blasting through the Earth's gravitational field, breaking into the silence of that place we label space. Why, he asks, do we "always have to reach 'escape velocity', all that power, all that burn; such a violence to access space – instead of what could be so gentle, this moment of floating?"

He envisages the 'Aerocene': an era with slower, solar-powered flight. In this quest, Saraceno is part of a movement which has not only already developed a portable solar balloon that can be launched by anyone anywhere, but also broke the world record for the world's most sustainable human flight – in Argentina in 2020.

"We were challenging how the history of aviation might move forward," Saraceno says of this mission, "and challenging the petro-capitalist fossil-fuel-based industry that is poisoning life on the planet."

Self described as "the sole artist in a family of scientists", Saraceno (below) has exhibited widely and co-authored scientific papers. His work Drift (opposite), in Brisbane, evokes both planetary and molecular space.

In answer to a question about the role of science in his work, Saraceno dives straight from the particulars of science as inheritance – "it's so much a part of my family heritage", he says of growing up the "sole artist in a family of scientists", with an agronomist father, a botanist mother – to the universal perspective of science combining with art to create "a wider cosmovision and other possibilities that are so needed in the world in crisis as it is".

He has collaborated with institutions including NASA, MIT, the Max Planck Institute, and the European Gravitational Observatory in Pisa – enjoying what he called "a challenge" with his good friend, its late director Stavros Katsanevas, about "whether spiders would be more sensitive than his gravitational wave detectors".

He has collaborated with arachnologists worldwide, including on earlier Australian field trips where he encountered *Maratus volans*, the gloriously bright Australian jumping spider. "This peacock spider, it's beautiful," he says. "The dance of this spider; it's amazing."

This sense of collaboration continues throughout Saraceno's arachnophilic and other nature-based work: the spiders create the webs that he displays in those glass tanks, and one new work for MONA – 'Leaf, Leaves, Life, Lives' – is an elegant series of

MONA/JESSE HUNNIFORD

DARIO LAGANA/STUDIO TOMAS SARACENO

collages made of leaves from Tasmania's forests. The six panels evoke life and decay, the traditional pressed-specimen collections of Western botany butting up against the ongoing vivacity of older, deeper indigenous knowledges.

In a way, every piece of *Oceans of Air* is a presentation of scientific observation as much as an artwork. Close-up images of single specks from NASA's extraordinary archive of cosmic dust – printed in ink made from black carbon PM2.5 pollution harvested from Mumbai. The audio-visual representation of some of the 25 million meteorite shards that hit Earth's atmosphere every day. The conversion of the movement of a strand of spider's silk in the breeze into song. Gentle footage of a diving bell spider (*Argyroneta aquatica*) that lives almost entirely underwater. ("It sounds like ghost wind," I hear one small girl say in the darkness.) The diptych that places a close-up of a spider's web alongside an image mapping the universe to reveal their structural similarities.

"I love Carl Sagan, you know; the cosmos," Saraceno explains. "So when I read in magazines that spiders' webs may have some correspondence with the cosmic web, I looked more attentively at that. And when you see spiders' webs after dawn, you know, with all the drops of water – you really see universes within universes."

"When you see spiders' webs after dawn, all the drops of water... you really see universes within universes."

Both Australian shows include sections of an ongoing project, "We do not all breathe the same air", which gathers long paper strips of data collected by Beta Attenuation Mass Monitors to make visible the different levels of particulate matter present in the air in different places.

To stand in the littoral zone that exists between science and art – in the overlays of creativity, observation, and imagination – is to run up against Leonard da Vinci, the most famous of polymaths, and a quote often attributed to him: "To develop a complete mind, study the science of art, study the art of science. Develop your senses, learn how to see. Understand that everything is connected."

At an existential level, rocketing towards – and beyond – that planetary boundary of 1.5°C and its implications for life – this call for connection has never been more urgent. It dovetails necessarily with the urgency of rendering the invisible visible (be that atoms, pollution, or the shape of the cosmos itself) and illuminating the unseen, the unknown, the unconsidered.

"This separation of knowledge into art, into science," says Saraceno: "we need them to come back together, to collaborate; to think in a much more family way." He pauses. "You know, in Columbian cultures, we have this term Pacha Mama, Mother Earth. The concept of pacha itself does not make the distinction between space and time like science does. It's much more a continuum, a 'quantum entanglement'. Only now is science trying to understand that."

ASHLEY HAY is based in Brisbane, her last story for the magazine, on the colour red, appeared in Issue 89.

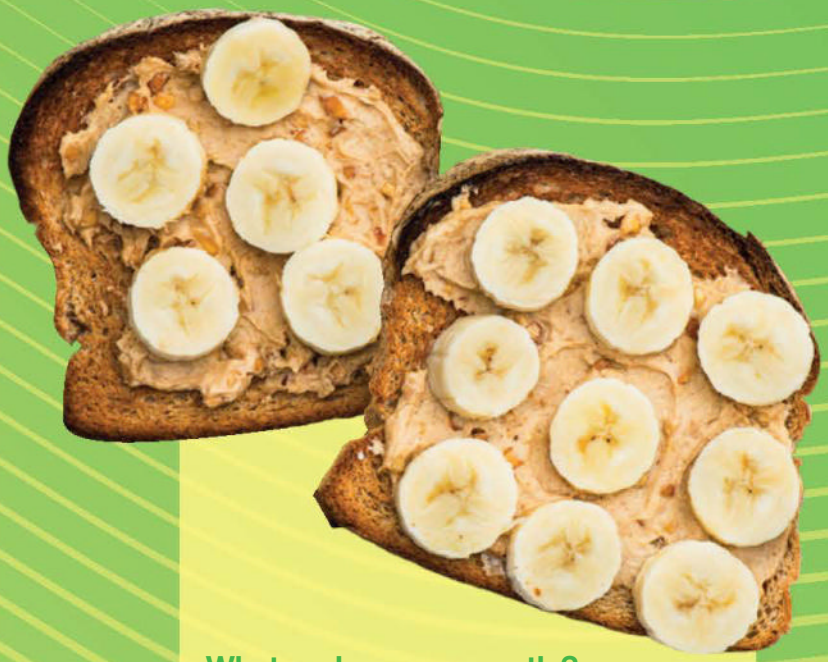
Commissioned especially for the MONA exhibition, "Oceans of Air", Leaf, leaves, life, lives (above) juxtaposes Western science collections and indigenous knowledge. Saraceno's studio describes Webs of At-tent(s)ion (opposite) as "a constellation of three-dimensional sculptures interwoven by unrelated spider species".

TOMAS SARACENO; MONA/JESSE HUNNIFORD

COOL BANANAS

Beloved by people the world over, bananas are delicious and nutritious. But are they in danger of extinction? Will eating too many kill you? And are banana peels *really* that slippery? **Imma Perfetto** takes a peek inside the fleshy yellow crescent...

BACKGROUND: BGBLUE / GETTY IMAGES. BANANAS: LEW ROBERTSON AND GLASSHOUSE IMAGES / GETTY IMAGES



Whether you prefer them in a smoothie, smooshed on toast with a bit of peanut butter, split and smothered in ice-cream and your favourite sticky topping, or just peeled and eaten plain, bananas are a universally crowd-pleasing fruit. Except, strictly, they're not a fruit (we'll get to that in a moment).

Cultivated bananas are the fourth most important crop in developing countries – after rice, wheat, and corn – and about 100 megatonnes are produced globally each year. To get an idea of what that looks like, they reckon the Great Pyramid of Giza weighs a little less than 6Mt. That's a lot of banana splits, yes? For some reason bananas seem to attract more myth and rumour than most cultivated objects.

Have you heard that bananas are all clones of each other? How about that they're going to go extinct one day because of a wickedly infectious banana disease? Let's peel back the skin on these, and some other, big banana facts and rumours.

"Cultivated bananas are the fourth most important crop in developing countries – after rice, wheat and corn – and about 100 mega tonnes are produced globally each year."

TOAST: MANUTA / ADOBE STOCK. WOMAN: ROHAPPY / GETTY IMAGES

What are bananas exactly?

Bananas are actually the berries of various flowering plant species in the genus *Musa*, which are native to tropical South-East Asia. Berry, not fruit, did I hear you say? Indeed you did. And will probably wish you'd brushed it off. It's a botanical thing, and somewhat chaotic, if you're a person that prefers order.

Botanists will tell you that berries have three distinct fleshy layers: an outer skin (exocarp), fleshy middle (mesocarp) and inner part that contains the seeds (endocarp). Berries also can't have a hardened woody endocarp (so peaches and cherries don't qualify), and they must develop from only one ovary within a single flower. So here's the fun: when you think through these qualities, surely then oranges are a berry? Aha: because oranges have distinct segments, they're a berry subtype called a hesperidium.

Just to be clear: the bananas we're talking about in this article are the sweeter forms that are generally eaten uncooked. The starchy, banana-like fruits that are cooked when they're less ripe are called plantains.

There are more than 1,000 different varieties within the genus *Musa*, but we're concerned with the cultivated varieties – not the wild ones. These edible domesticated varieties come from a genetic mutation that resulted in the seedless fruit we know today.

Domesticated bananas are parthenocarpic, which means that the fruit grows without seed development or pollination and fertilisation. In other words, they're tasty but sterile, so to propagate them you have to clone them.

That's not as sci-fi as it sounds, because banana plants produce these things called "suckers", which are shoots that develop from the stem of the plant. These suckers can be cut off and planted, after which they grow into a genetically identical fruit-producing plants. This is a pretty routine plant propagation

process, and you can do it at home with many of your own houseplants.

Unfortunately, this makes bananas incredibly vulnerable to disease outbreaks because there's no genetic diversity. So, if one plant in a variety is susceptible to a disease, they all are.

How do we know this? Through experience.

The popular dessert bananas you're familiar with are a subgroup of varieties named Cavendish. They dominate the market today, making up around 50% of global banana production and about 95% of exports.

But the Cavendish wasn't always the crowd favourite. Until the 1950s, Gros Michel, or 'Big Mike', was the number one variety grown in commercial banana plantations.

That was until a fungal disease called fusarium wilt, or Panama disease, nearly wiped them out completely. The disease is caused by the fungus complex *Fusarium oxysporum* and was first reported in Australia in 1874, before spreading to nearly all banana-growing regions.

Fusarium is a soil pathogen that infects the plants' root and vascular system and makes them unable to transport essential water and nutrients, and it forced the banana industry to cultivate Fusarium-resistant Cavendish varieties instead.

(Cool Fusarium fact: the fungus is able to dissolve gold, then precipitate it onto its surface, thus coating itself with gold. CSIRO scientists first observed this at Boddington, West Australia, and published the finding in *Nature Communications* in 2019. They posited that *F. oxysporum* might be of help in detecting hidden underground gold reserves.)

You're probably thinking "thank goodness for Cavendish".

Well, yes – at least up until the emergence of an extremely virulent strain of fusarium wilt known as Tropical Race 4 (TR4).

Cavendish, and other Australian-grown varieties, are vulnerable to TR4. It was first detected in South-East Asia in the 1990s but has since spread to Australia, East Asia, Africa, and recently South America.

Once Fusarium fungus is established in an area, it can't be removed through chemical or physical means. The only way to protect bananas is to prevent the fungus from spreading, or to develop resistant banana varieties.

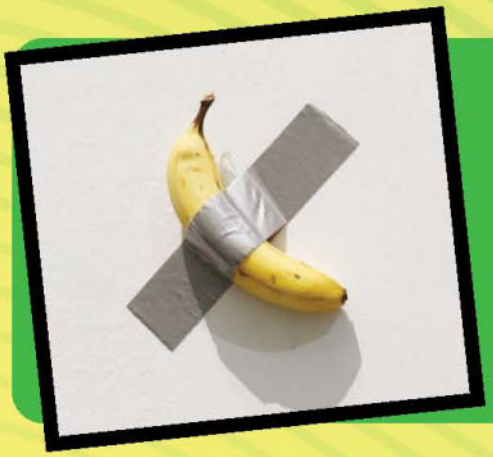
Scientists are improving diagnostic tools to locate TR4, and are using breeding and genetic engineering to try to create resistant varieties. One approach has scientists introducing antifungal genes from other plant species; in another, a resistance gene from the TR4-resistant wild banana *Musa acuminata ssp malaccensis*, has been introduced into Cavendish varieties.

A recent study published in *PLOS One* found that scientists could induce disease resistance by inoculating Cavendish bananas with a non-virulent form of the Fusarium strain called Race 1.

Death... by banana

Have you heard that eating too many bananas could kill you – or at least make you very sick? This isn't about over-eating; according to the rumour mill, bananas can give you a fatal overdose of potassium, or a deadly exposure to radiation.

Bananas are a good source of potassium and too much potassium can sometimes lead to a fatal condition called hyperkalemia, which can be caused by kidney failure, heavy alcohol use, low red-blood-cell count, or overdosing on potassium supplements.



COMEDIC ART

Italian conceptual artist Maurizio Cattelan's 2019 work *Comedian* (left) became a fruit sensation when it was entered into Art Basel Miami Beach. It is, as shown at left, a real banana, duct-taped to a wall. Two editions of the certified art piece sold for US$120,000.

After the exhibition, performance artist David Datuna ate the exhibit in an intervention he called *Hungry Artist*.

"Conceptually, I ate the concept of the banana," Datuna told *Vogue*. "It tasted like $120,000. It was delicious."

BUNCH: FLAVIO COELHO / GETTY IMAGES. TAPED BANANA: CHINA NEWS SERVICE / GETTY IMAGES.

RIPENING RULES

Ever wondered why putting new, green bananas next to older, brown ones makes them ripen quicker? It's because bananas are what's known as a climacteric fruit, which continue to ripen after picking – it's a group that includes pears and avocados.

Green bananas store energy as starch, which is a long carbohydrate or sugar polymer that doesn't taste sweet. They begin to ripen when exposed to the plant hormone ethylene, which kick-starts the process.

Stored starch is converted into simpler sugars that taste sweet, and the fruit begins to produce its own ethylene, which further speeds ripening.

"A medium banana contains about 420mg of potassium, so you'll have to eat 11 in one day just to meet the 4700mg daily allowance of potassium for adults and children older than four."

A medium banana contains about 420 milligrams of potassium, so you'd have to eat 11 in one day just to meet the 4700mg recommended daily allowance of potassium for adults and children older than four years.

There's no established upper limit of potassium intake, but oral doses of more than 18 grams may lead to hyperkalemia. You'd need to eat 42 bananas in a short period to achieve this result.

But what about radiation? In fact, bananas are slightly radioactive, thanks to a particular isotope called potassium-40.

All atoms of the same element have the same number of protons, but they don't always have the same number of neutrons – these are what are known as isotopes. Radioactive isotopes aren't stable, and they break down, releasing energy as radiation.

Naturally occurring potassium has three isotopes, one of which, potassium-40, is radioactive. Potassium-40 makes up about 0.012% of the total amount of potassium found in nature.

The potassium-40 dose you get from eating one banana will expose you to roughly 1% of your average daily exposure to background radiation. To get over the line to a lethal dose of radiation you'd need to eat 35 million bananas in a day.

Really: how slippery are banana peels?

If you've ever played Mario Kart, you'd know that banana peels can stop you right in your tracks. But are banana peels actually that slippery?

In a 2012 study in the journal *Tribology Online*, Japanese researchers from Kitasato University measured the friction coefficient under Cavendish banana skins.

A lower coefficient of friction implies that a surface is more slippery. Their experiment simulated a slipping accident under a sliding shoe and found that banana peels have a friction coefficient of 0.07. For context, surfaces with a friction coefficient of less than 0.1 are considered well lubricated, like ice on ice.

Further inspection under a microscope revealed that banana skins are lined with lots of tiny sacs of a gooey substance called polysaccharide follicular gel.

When the peel is crushed under foot, these substances are released and combine to make a slippery solution that forms a lubricating film between the shoe and surface.

It has been a pleasure pealing on about bananas, and there's probably a bunch more things I could write, but I've got to split. As Groucho Marx is reputed to have said: "Time flies like an arrow; fruit flies like a banana."

IMMA PERFETTO is a science journalist at Cosmos. This is her first story for the magazine.

Hear *Cosmos* journalists explain all of life's big and small questions on our weekly podcast: *Huh? Science Explained*

GREEN BANANA: ROSEMARY CALVERT / GETTY IMAGES. STOMPED BANANA: WESTEND61 / GETTY IMAGES

WHERE IN THE COSMOS?

Send us a pic of where you're reading Cosmos to win a limited edition notebook.

Two if by sea

Hiding in Hyde Park on her lunch break with Cosmos, Rachel Fieldhouse wrote: "The duckweed and turtle tales made this slice of nature in the heart of Sydney's CBD even more heavenly." Meanwhile, our second letter came paddling in from Paul van Leeuwen in Port Phillip Bay. We'd love to see where you're reading! Please send us a shot of your special science place: contribute@cosmosmagazine.com.

GUESS WHO?

Question

Whose Law?

Decode where n = ■

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Hint:

He was a nineteenth century German scientist at the University of Rostock.

MIND GAMES

NO.24

Who Said?

"Science is organised knowledge. Wisdom is organised life." (8,4)

	1	2	3	4	5	6	7	8	9	10	11	12
I	■			■		■			■		■	
II				■								
III												
IV												
V												
VI												
VII												
VIII												
IX			■					■		■		
X		■	■		■	■		■		■		

Instructions

Answers to each of the clues in columns 1 to 12. Row VI reveals the answer.

Clues and columns

1 First produced in 1944 as part of the Manhattan Project, which synthetic element has the atomic number of 95? (9)

2 In 1986 who founded *Australian Geographic*? (4,5)

3 From the Greek, what is the medical word for "pulse"? (8)

4 What adjective relates to the earliest principal division of the Mesozoic era? (8)

5 What is the natural phenomena whereby a star can become up to 108 times brighter than the sun? (9)

6 What was the surname of the Italian navigator whose first name, Amerigo, was applied to the Americas by the German cartographer Waldseemüller on his 1507 map *Universalis Cosmographia*? (8)

7 In economics, what is the leading indicator of aneconomic trend? (10)

8 In which city is the flagship campus of the University of California? (8)

9 Which Australian won the 2009 Nobel Prize in Physiology or Medicine? (9)

10 In 1965, in Renmark, what did Tom Angove invent? (4,4)

11 What is the group of fossil specimens of *Homo erectus* discovered in 1929-37 at an excavation near Beijing? (6,3)

12 Which branch of medicine cares for women during pregnancy and childbirth? (10)

COSMOS CODEWORD

NO.24

Codeword requires inspired guesswork. It is a crossword without clues. Each letter of the alphabet is used and each letter has its own number. For example, 'A' might be 6 and 'G' might be 23 .

Through your knowledge of the English language you will be able to break the code. We have given you three letters to get you started.

12	4	9	10	12	23	12	1	■	22	11	24 B	23	15	26
24	■	19	■	4	■	6	■	7	■	24	■	3	■	12
13	15	19	6	15	3	10	■	18	12	3	23	1	11	13
15	■	7	■	21	■	8	■	7	■	1	■	■	■	13
20	12	23	19	7	4	■	11	26	11	21	7	10	15	11
15	■	24	■	■	■	21	■	19	■	11	■	15	■	2
12	23	15	5	15	1	11	13	■	25	1	12	26	25	8
1	■	3	■	17	■	1	■	5	■	26	■	23	■	7
■	11	10	11	17	7	21 D	■	23	6	7	24	12	25	■
26	■	■	■	11	■	7	■	12	■	■	■	8	■	15
11	22	19	7	23	5	13	12	16	■	8	11	26	■	1
13 L	■	12	■	21	■	15	■	■	■	14	■	12	■	8
15	10	2	11	8	19	12	■	19	23	3	10	2	7	19
26	■	15	■	■	■	1	■	7	■	11	■	15	■	7
12	23	26	6	15	21	■	6	11	1	21	15	26	11	2

1	2	3	4	5	6	7	8	9	10	11	12	13
14	15	16	17	18	19	20	21	22	23	24	25	26

ALL PUZZLES DESIGNED AND COMPILED BY SNODGER.COM.AU

IT FIGURES

NO.24

	1	2	3	4
A				
B				
C				
D				

Instructions

Using the clues below place the numbers 1 to 16 correctly in the grid. How many clues do you need?

Level 1 – Chief Scientist

1. The product of the numbers in each of the first three rows create factors of 1440.
2. The upward sloping diagonal contains three multiples of 5.
3. The numbers in every row are written in ascending order.
4. The sum of the numbers in Row B is 36.
5. No row contains more than two square numbers.

Level 2 – Senior Analyst

6. Row C begins with three consecutive numbers.
7. The sum of the first three numbers in Column 1 is equal to the last.

Level 3 – Lab Assistant

8. The product of the first and last numbers in Column 2 is 88.

SOLUTIONS: COSMOS 97

CODEWORD

L	Y	M	P	H	O	I	D	■	F	R	E	E	Z	E
I	■	I	■	U	■	G	■	A	■	E	■	T	■	■
G	A	L	L	E	O	N	■	S	O	M	E	H	O	W
A	■	L	■	■	■	O	■	Y	■	A	■	N	■	R
M	A	E	L	S	T	R	O	M	■	S	P	O	K	E
E	■	N	■	I	■	A	■	P	■	T	■	G	■	N
N	O	N	A	G	O	N	■	T	H	E	O	R	Y	■
T	■	I	■	N	■	C	■	O	■	R	■	A	■	E
■	T	A	X	I	D	E	R	M	Y	■	A	P	E	X
A	■	■	■	F	■	■	■	A	■	W	■	H	■	A
B	A	N	D	I	C	O	O	T	■	A	B	Y	S	M
A	■	A	■	C	■	R	■	I	■	L	■	■	■	I
C	A	S	S	A	V	A	■	C	O	N	J	O	I	N
U	■	A	■	N	■	T	■	■	■	U	■	R	■	E
S	P	L	I	T	■	E	Q	U	I	T	A	B	L	E

1 J	2 C	3 D	4 Z	5 W	6 P	7 Q	8 T	9 F	10 U	11 X	12 K	13 A
14 I	15 R	16 N	17 E	18 B	19 M	20 L	21 H	22 Y	23 V	24 O	25 G	26 S

IT FIGURES

9	8	14	5
12	16	7	13
3	1	6	2
10	4	11	15

WHO SAID?

Tschichold

A German calligrapher, typographer and book designer, Jan Tschichold played a significant role in the development of graphic design in the 20th century.

■	K	B	■	E	S	■	■	Y	■					
E	O	A	R	R	A	■	B	E	E					
T	S	C	H	I	C	H	O	L	D					
Y	C	T	E	O	C	E	D	L	W					
M	I	E	O	S	H	S	L	O	I					
O	U	R	S	T	A	S	E	W	N					
L	S	I	T	E	R	S	I	C	L					
O	Z	A	A	M	I	L	A	A	A					
G	K	■	T	O	N	A	N	K	N					
Y	O	■	■	N	■	W	■	E	D					

WHOSE LAW? ANSWER:

Equal volume of all gases under the same conditions of temperature and pressure contain equal number of molecules. *Avogadro*

Jen Sanger

Canopy ecologist

Jen Sanger has always been a plant nerd, but it was in the high-elevation cloud forests of Mexico that she realised her true passion: the worlds of the canopy, far above our heads.

"I came across these forests, and there were just whole gardens of epiphytes, like a forest within a forest," Sanger recalls.

Epiphytes are plants that grow on another plant, like a fern, orchid, moss or lichen. They aren't parasitic, Sanger says: "They're just using the tree as structure."

Sanger had completed her honours degree in plant physiology, studying an endangered eucalypt on the frozen central plateau of Tasmania/lutruwita.

She took off travelling for several years. Then, the cloud-forest epiphytes of Mexico reminded her of her undergraduate degree at the University of Queensland, where she'd volunteered for a study looking at insects in tropical Australian rainforests, in which tree climbers were a critical element.

The idea for a PhD was born. But finding a supervisor was tricky. "There was literally only one guy who did his PhD in the '80s who had studied epiphytes in Australia," Sanger says – James Kirkpatrick at the University of Tasmania (UTAS), who ended up being her supervisor.

With a tree-climbing course in the US under her belt, Sanger embarked on her PhD at UTAS to look at the diversity of epiphytes in rainforest canopies. She spent her winters climbing and collecting data in tropical Queensland with her husband, Steve Pearce, as her research assistant. Together, they climbed around 250 trees for her thesis.

> Going up into the canopy of these trees was just a whole other experience.

"The thing that we really discovered was this new way of looking at the forest," Sanger says. "Here I was as a forest ecologist who thought I knew forests really well, but going up into the canopy of these trees was just a whole other experience."

Along with colleagues in New Zealand/Aotearoa, Sanger and Pearce, an accomplished photographer, developed a technique to take whole-tree portraits, by melding a series of images taken from a neighbouring tree. They've captured many stunning portraits, including giant eucalypts in Tasmania and others around the world, from Taiwan to the US.

They also founded The Tree Projects to generate interest in Tasmania's forests. Their approach seems to reflect new approaches in science.

"Everyone used to think it was survival of the fittest, and all these trees are fighting one another for resources," Sanger says. "But in reality, it's a lot more beneficial to cooperate as a community rather than just trying to fight it out on your own."

EXPLORE MORE ABOUT TASMANIA'S TALLEST TREES ON PAGE 62

LEFT: ROB BLAKERS. ABOVE: IAN CONNELLAN

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